Benchmarking the environmental performance of specialized dairy production systems: selection of a set of indicators

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ABSTRACT

Benchmarking the environmental impacts of dairy production systems across the world can provide insights into their potential for improvement. However, collection of high-quality data for an environmental impact assessment can be difficult and time consuming. Based on a dataset of 55 dairy farms from different countries, this study aims to identify an effective set of indicators, that can explain most variation between farms and is relatively easy to quantify. Results show that global warming potential (GWP) per kg milk was highly correlated with nitrogen balance (NB) (r= 0.73, P<0.01) per kg milk, land use per kg milk (r= 0.58, p<0.01) and energy use per kg milk (r= 0.74, P<0.01). Correlations between phosphorus balance (PB) per kg of milk and other indicators, however, were low. Consequently, results of principal component analysis yielded two factors. The first factor consisted of GWP, NB, land use and energy use, all expressed per kg of milk, whereas the second factor contained PB per kg milk. We concluded, therefore, that GWP and PB can be used as proxies to benchmark specialized milk production systems across the world.

Keywords: life cycle assessment, nutrient balance, milk production, correlation analysis

1. Introduction

Milk is an important protein source in human diets. Around 57% of the protein content of an average European diet consists of livestock products, of which about one third is milk-derived (FAOSTAT 2013). The global demand for milk is expected to increase further due to population growth, rising incomes and on-going urbanization. Dairy production, however, has a major impact on the environment. The global dairy sector, producing both milk and meat, is responsible for about 30% of the anthropogenic greenhouse gas (GHG) emissions from livestock (Gerber et al. 2013). Moreover, the dairy sector contributes to resource scarcity (e.g. land and fossil energy) (De Vries and De Boer 2010).

Various environmental assessment methods have been adopted to evaluate the environmental performance of dairy production systems. Two methods are commonly used in the field of agriculture. The first method is based on a nutrient balance, and yields indicators such as nutrient use efficiency and the nutrient balance per unit product. The second method is based on life cycle assessment (LCA), and yields indicators such as global warming potential per unit product or land occupation per unit product (Halberg et al. 2005). Both methods, however, have their own drawbacks. On the one hand, a nutrient balance neglects certain environmental impact categories (e.g., land use, energy use); on the other hand, although LCA incorporates environmental impact categories which are overlooked by a nutrient balance, it is difficult and time consuming to collect all the data required to perform an LCA (Thomassen and De Boer, 2005). For cross-border benchmarking, the simplicity of the indicator sets can be very essential. The aim of this study, therefore, is to select an effective set of indicators from above mentioned methods, that can be used to benchmark the environmental performance of specialized dairy production systems.

Exploring correlations between various indicators can help stakeholders to identify an effective set of indicators to evaluate the environmental performance of dairy farms, i.e. a set of indicators which is relevant, needs a minimal amount of data and is understandable (Lebacq et al. 2013). Previous studies have focused mainly on correlations between indicators within LCA. Their findings suggested that the number of indicators may be reduced because of strong correlation between some indicators (Berger and Finkbeiner 2011; Huijbregts et al. 2010; Laurent et al. 2012; Röös et al. 2013). So far, however, correlations between various indicators derived from a nutrient balance approach and LCA have not been explored within dairy production systems.

The objective of this study is to identify an effective set of indicators to benchmark the environmental performance of dairy production systems. We, therefore, explored correlations between indicators derived from a nutrient balance and from an LCA and see whether we can have a set of simplified indicators that can be used as proxies to benchmark environmental performances of dairy farms.

2. Material and methods

2.1. Data

Data was collected from 55 specialized dairy farms from Dairyman which is a project in the INTERREG IVB program co-funded by the European Regional Development Fund (Dairyman 2010). Environmental performance of these farms has been determined based on different indicators using data of the year 2010. We defined specialized farms as farms that have less than 5% non-dairy purpose animals, and less than 10% of their agricultural area in use for non-dairy purpose activities. The amount of energy, land and fertilizers used for non-dairy purposes was based on farmers' estimates and excluded from the data set. These 55 dairy farms are from different countries and regions (i.e. Netherlands, Ireland, Belgium (Flanders, Wallonia), France (Brittany), Germany (Baden, Württemberg) and Luxembourg).

2.2. System boundaries

As illustrated in Figure 1, we defined different system boundaries for different methods (i.e. nutrient balance and LCA). For the nutrient balance, we examined the farms' performances both at farm and partial chain level. At the farm level, we considered inputs (e.g. concentrates, roughage, animal) and outputs (e.g. milk, meat, crops) per farm, while the farm itself was considered as a black box. At the partial chain level, the system boundary was from cradle-to-farm gate. In addition to nutrient losses at the farm, nutrient losses during the production of purchased feed products were considered. Production of other farm inputs were excluded because their contribution to nutrient losses was assumed to be negligible. For both farm and partial chain levels, manure outputs of the farm were deducted from the input of the system. Stock changes (defined as final stock – initial stock) of the concentrates, roughages and fertilizers were taken into consideration during the computation processes.

For LCA, the system boundary was from cradle-to-farm gate. System boundaries, therefore, included the primary production of farm inputs, and all processes on the farm, such as manure management, milk and feed production. Pesticides and water usage were not considered due to lack of data. Capital goods (buildings and machinery) were not considered because their contributions to the environmental impact of dairy farming were assumed to be negligible (Cederberg 1998).

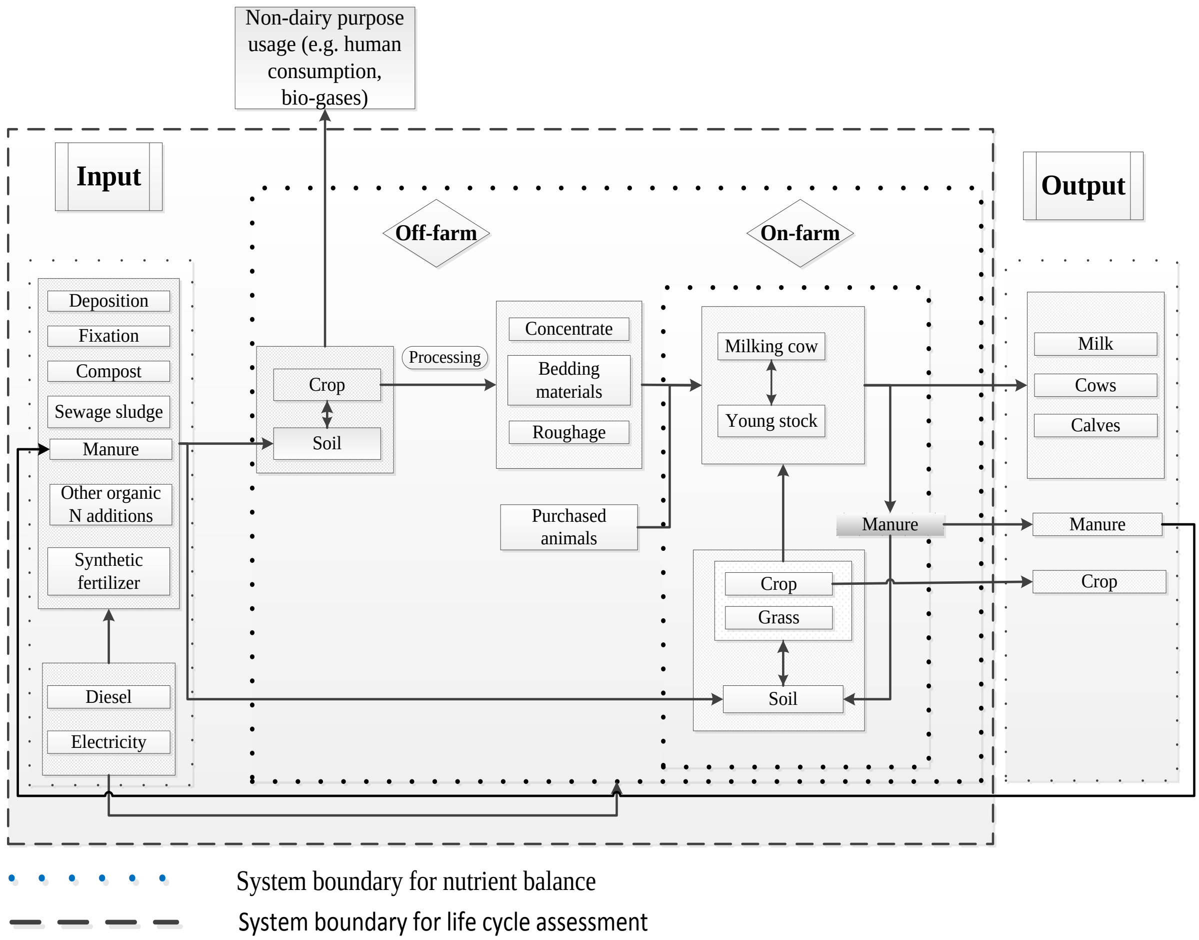

Figure 1. System boundaries

2.3 Nutrient balance

Nitrogen (N) and phosphorous (P) are essential nutrients for plant and animal production. The increased use of N and P for food production, however, also increased emissions of N and P compounds to the environment (Amon et al. 2011). In this study, based on N and P content in all inputs, outputs and stock changes of the systems, we computed N balance (NB) and P balance (PB) for each of the 55 dairy farms both at the farm level and partial chain level. The partial chain level nutrient balance was calculated by summing up the nutrient balance at farm level and the nutrient balance related to production of purchased feed products. Nutrient balance was defined as input-output and was expressed as nutrient balance / kg FPCM (fat-and-protein-corrected milk, i.e. milk is corrected to a fat percentage of 4.0% and a protein content of 3.3% using the formula: FPCM (kg) = Milk (kg) x [0.337 + 0.116 x Fat (%) + 0.06 x Protein (%)] (Product Board Animal Feed 2008)). Table 1 shows relevant inputs, outputs and calculation processes.

Table 1. Nutrient use efficiency for nitrogen and phosphorus

Elements	Calculation[4]	References
Input:		
Purchased animals	Q x nutrient content of animals	Raison et al. 2006
Purchased roughage[1]	Q x nutrient content of roughage	Dairyman 2010
Purchased concentrate	Q x nutrient content of concentrates[5]	Dairyman 2010
Purchased mineral fertilizer	Q x nutrient content of mineral fertilizer	Dairyman 2010
Purchased organic fertilizer	Q x nutrient content of organic fertilizer	Dairyman 2010
Atmosphere deposition	Average value of relevant region	EMEP 2007
Plant fixation[2]	Average value of relevant region	Raison et al. 2006
N&P input for producing feed[3]	N&P input for producing feed	Vellinga et al. 2013
Output:		
Milk output	Q x nutrient content of milk	Dairyman 2010
Animal output	Q x nutrient content of animals	Raison et al. 2006
Organic fertilizer output	Q x nutrient content of organic fertilizer	Dairyman 2010
Plant outputs	Q x nutrient content of plant	Raison et al. 2006

[1] We selected five most commonly used roughages in the dataset of Dairyman, i.e. grass silage, maize silage, hay, wheat straw and alfalfa.
[2] Plant fixation is only applicable for nitrogen
[3] Applicable for nutrient balance calculation at the partial chain level
[4] Q= actual quantity of product purchased or sold, obtained from Dairyman (in kg or numbers)
[5] Composition of the concentrate is based on the information provided by Dairyman

2.4. Life cycle assessment

The impact categories we examined are climate change, land use, and fossil energy use. The functional unit is FPCM. The computation for climate change is described in details in the following subsection.

Climate change. We used global warming potential (GWP) per kg FPCM as an indicator to assess the impact of milk production on climate change. GWP included emissions of the greenhouse gases (GHGs): CO_2, CH_4 and N_2O and was expressed in kg CO_2 eq per kg FPCM. Emissions of GHGs were summed according to the following equivalence factors (100-year time horizon): 1 for CO_2, 25 for CH_4, and 298 for N_2O (Forster et al. 2007).

We computed on-farm emissions of GHGs according to IPCC guidelines (IPCC 2006), generally at Tier-2 level. On-farm emissions included CO_2 emissions from lime and urea application, and combustion of energy resources, such as diesel; CH_4 emissions from enteric fermentation and manure management, and N_2O emissions from manure management and managed soils.

To compute CO_2 emissions from lime and urea application, we used the default emission factor of 0.12 for limestone, 0.13 for dolomite and 0.2 for urea as provided by IPCC (2006) Tier 1. To compute CO_2 emissions from on-farm energy use (i.e. fuel), we used emission factors from Eco-invent (2010).

Enteric CH_4 emission was determined as a function of the average gross energy (GE) intake of the dairy herd and a methane conversion factor of 6.5% (IPCC, 2006). Average GE intake of the dairy herd was calculated based on the total net energy requirement of the herd (i.e. energy required for growth, maintenance, activity, and milk production) and energy availability characteristics of feeds. CH_4 emissions from manure management were calculated based on the amount of volatile solids in manure and manure management system (IPCC, 2006).

During storage, treatment and application of manure, N_2O is emitted via direct and indirect pathways. Direct N_2O emissions from manure storage and treatment were calculated by multiplying the total amount of N excretion within a certain manure management system with an emission factor for that type of system (IPCC, 2006). Direct N_2O emissions from manure application were calculated by multiplying the amount of N in manure applied to the field with the default emission factor of 0.01 (IPCC, 2006). Indirect N_2O emissions were based on the amount of N volatilized in the form of NH_3 and NO_x, and the amount of N leached in the form of NO_3 (IPCC, 2006). In addition, direct and indirect N_2O emissions from application of synthetic fertilizer, crop residues, and from urine and dung deposited on pasture during grazing were included and based on IPCC (2006) calculation rules.

Off-farm GWP was calculated based on GHG emissions from production and transportation of purchased feed (e.g. concentrates, roughages, by-products and from production of synthetic fertilizer. Concentrates were categorized into four categories: cereals (i.e. wheat, barley, triticale, oat, and corn), rapeseed meal, soya meal, and other. GHG emissions related to production of purchased feed products were based on Vellinga et al. (2013). GHG emissions related to production of fertilizers were based on Ecoinvent (2010).

Land use. This impact category examines the area of land (m^2) used to produce one kg FPCM. For on-farm land use, we considered agricultural area used for dairy purpose. For off-farm land use, we considered land used for cultivation of concentrate ingredients, roughage and by-products (Vellinga et al. 2013), and for the production of fertilizers (Ecoinvent, 2010).

Energy use. On-farm energy use relates to milking of the dairy cows and on-farm feed production, and is based on Dairyman (2010). Off-farm energy use related to the production of purchased feed products was based on Vellinga et al. (2013); energy use related to the production of fertilizers was based on Ecoinvent (2010). We assumed that energy used in this study are electricity and diesel.

2.5 Statistical analysis

Principle component analysis (PCA) was applied to characterize the indicators to get an efficient set of indicators that can explain most of the variation. We applied PCA on seven indicators at the chain level i.e. NB, PB, GWP, land use and energy use. Spearman Rho's correlation analysis was conducted due to the fact that most variables are not normally distributed. After that, we did Kaiser-Meyer-Olkin test (KMO>0.5) and Bartlett's Test of Sphericity ($p<0.05$) in order to assure the adequacy of data sampling and suitability to conduct the PCA. We selected factors based on the rule of eigenvalue > 1. All statistical analyses in this study were performed using the software SPSS (SPSS 2011).

In order to interpret correlations identified from correlation analysis, we used the criterion in Cohen (1998, as cited in Röös et al. 2013), where defines r=0.1-0.29 (weak correlation), r=0.30-0.49 (medium correlation) and r=0.5-1 (strong correlation).

3. Results

3.1. Nutrient balance

As shown in Table 2, for nitrogen, the average farm balance/kg FPCM is 16g N, whereas the average chain balance/kg FPCM is 19g N; for phosphorous, the average farm balance/kg FPCM is 1g P, whereasthe average chain balance/kg FPCM is 2g P.

Table 2. Results of nutrient balance

Indicator	Unit	Mean	SD	Maximum	Minimum
Nitrogen					
Farm balance	g N / kg FPCM	16	8	34	4
Chain balance	g N / kg FPCM	19	7	37	6
Phosphorous					
Farm balance	g P / kg FPCM	1	1	3	0
Chain balance	g P / kg FPCM	2	1	8	1

3.2. Life cycle assessment

According to Table 3, producing one kg FPCM contributes to climate change (1.31 kg CO_2 eq), meanwhile, it uses 1.29 m^2 land and 2.92 MJ energy. On-farm processes have a larger impact on climate change and land use than off-farm processes. However, off-farm processes use more energy than the on-farm processes. Finally, variation between farms is greater for on-farm processes than for off-farm processes.

Table 3. Results of LCA

Impact category	Unit	Mean	SD	Maximum	Minimum
Climate change	kg CO_2 eq / kg FPCM				
On-farm		1.08	0.25	1.76	0.75
Off-farm		0.23	0.81	0.54	0.04
Total		1.31	0.29	2.08	0.94
Land use	m^2 / kg FPCM				
On-farm		0.82	0.38	2.23	0.32
Off-farm		0.47	0.21	1.48	0.11
Total		1.29	0.45	2.80	0.76
Energy use	MJ / kg FPCM				
On-farm		0.53	0.15	1.11	0.21
Off-farm		2.39	0.69	4.74	1.28
Total		2.92	0.74	5.26	1.49

3.3. Statistical analysis results

Results of correlation analysis are reported in Table 4. NB shows low correlation with PB (r= 0.04). GWP shows strong correlations with NB (r= 0.73, P<0.01), land use (r= 0.58, p<0.01), and energy use (r= 0.74, P<0.01). Energy use shows strong correlation with NB (r= 0.57).

A positive nutrient balance can cause emissions like N_2O which is a major contribution to the GWP, therefore GWP shows a strong positive correlation with NB. Land use and GWP are both expressed per kg FPCM. A possible explanation for the correlation between land use and GWP is that farms that are less efficient will have a lower milk production per ha (i.e. a higher land use), but also higher losses and, therefore, higher GHG emissions per kg FPCM. In addition, during production and use of energy, there are emissions like CO_2 and N_2O. All these emissions can increase GWP, therefore a high positive correlation is found between GWP and energy use.

The results of Kaiser-Meyer-Olkin (KMO) test and Bartlett's Test confirmed the suitability of conducting a PCA (principal component analysis). Sampling size is adequate (KMO= 0.655) and Bartlett's test of sphericity is significant (p= 0.000). Two factors were extracted from PCA, where NB, GWP, land use and energy use are grouped into one factor and PB is grouped into the second factor. The first factor can explain 58% variation existing in the data, and by also considering the second factor, total 79% variation existing in the data can be explain.

Table 4. Results of correlation analysis

	N balance	P balance	GWP	Land use	Energy use
N balance[1]	1	0.037	0.728^{**}	0.359^{**}	0.567^{**}
P balance[1]	0.037	1	-0.220	0.082	-0.211
GWP	0.728^{**}	-0.220	1	0.584^{**}	0.739^{**}
Land use	0.359^{**}	0.082	0.584^{**}	1	0.498^{**}
Energy use	0.567^{**}	-0.211	0.739^{**}	0.498^{**}	1

** Correlation is significant at the 0.01 level (2-tailed)
* Correlation is significant at the 0.05 level (2-tailed)
[1] N balance and P balance here are both at the chain level.

4. Conclusion

Results of the correlation analysis show that global warming potential (GWP) per kg milk was highly correlated with nitrogen balance (NB), land use, and energy use. Correlations between phosphorous balance (PB) and other indicators, however, appeared to be low. Consequently, results of PCA yielded two factors. The first factor consisted of the indicators GWP, NB, land use and energy use, whereas the second factor contained PB. Therefore, we concluded that GWP and PB can be used as proxies to benchmark specialized milk production systems across the world. Future studies might include other environmental indicators, such as eutrophication potential and acidification potential, to further explore possibilities for identifying an effective set of indicators to benchmark environmental performance of dairy production systems.

5. References

Amon B, Hutchings N, Vinther F, Nielsen P, Poulsen H, Kristensen S, Pietrzak S (2011) Analysis of methodologies for calculating greenhouse gas and ammonia emissions and nutrient balances. European Commission. http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-RA-11-024/EN/KS-RA-11-024-EN.PDF. Accessed 11 February 2014

Cederberg, C (1998) Life cycle assessment of milk production – a comparison of conventional and organic farming SIK. Report No.643. The Swedish Institute for Food and Biotechnology, Goteborg, Sweden, pp. 1–86.

Cohen, J (1988) Statistical Power Analysis for the Behavioral Sciences, 2nd edn. Lawrence Erlbaum Associates Inc, Abingdon

Raison C, Pflimlin A , le Gall A (2006) Study of the distribution of nitrogen surplus in experimental dairy farms of the Atlantic area. Dairy Systems and Environment in the Atlantic Area. Proceedings of the Final Seminar of the Green Dairy Project, Institute of de I'Elevage, Rennes

Berger M , Finkbeiner M (2011) Correlation analysis of life cycle impact assessment, indicators measuring resource use. Int. J. Life Cycle Assess 16: 74–81.

Dairyman (2010) A project in the INTERREG IVB program co-funded by the European Regional Development Fund. http://www.interregdairyman.eu/en/dairyman.htm. Accessed 15 December 2013

De Vries M, De Boer IJM (2010) Comparing environmental impacts for livestock products: a review of life cycle assessments. Livest Sci 128(1–3):1–11

EMEP (2007) Co-operative programme of the monitoring and evaluation of the long range transmissions of air pollutants in Europe. http://www.nilu.no/ projects/ccc/emepdata.html. Access 11 December 2013

EcoinventCentre (2010) Ecoinvent data v2.2. Final reports econinvent 2010. Swiss Centre for Life Cycle Inventories, Dübendorf

FAOSTAT (2013) FAO statistical databases: agriculture, fisheries, forestry, nutrition. crop statistics. FAO—Food and Agriculture Organization of the United Nations, Rome

Forster P, Ramaswamy V, Artaxo P, Berntsen T, Betts R, Fahey DW, Haywood J, Lean J, Lowe DC, Myhre G, Nganga J, Prinn R, Raga G, Schulz M, Van Dorland R (2007) Changes in atmospheric constituents and in radiative forcing. Climate change 2007: the physical science basis. Cambridge University Press, Cambridge

Vellinga TV, Blonk H, Marinussen M, Van Zeist WJ, De Boer IJM (2013) Methodology used in feedprint: a tool quantifying greenhouse gas emissions of feed production and utilization. Lelystad, the Netherlands,http://edepot.wur.nl/254098. Accessed Dec 2013

Gerber PJ, Steinfeld H, Henderson B, Mottet A, Opio C, Dijkman J, Falcucci A, Tempio G (2013) Tackling climate change through livestock – A global assessment of emissions and mitigation opportunities. Food and Agriculture Organization of the United Nations, Rome.

Halberg N, van der Werf HMG, Basset-Mens C, Dalgaard R, de Boer I (2005) Environmental assessment tools for the evaluation and improvement of European livestock production systems. Livest Prod Sci 96:33–50

Huijbregts M, Hellweg S, Frischknecht R, Hendriks H, Hungerbuler K, Henriks J (2010) Cumulative energy demand as predictor for the environmental burden of commodity production. Environ. Sci. Technol 44: 2189–2196

IPCC (2006) Intergovernmental Panel on Climate Change. Guidelines for national greenhouse gas inventories. Volume 4: agriculture, forestry and other land use. Prepared by the National Greenhouse Gas Inventories Program. Eggleston HS, Buendia L, Miwa K, Ngara T, Tanabe K (eds). IGES, Japan

Laurent A, Olsen SI, Hauschild MZ (2012) Limitations of carbon footprint as indicator of environmental sustainability. Environ Sci Technol 46:4100–8

Lebacq T, Baret PV, Stilmant D (2013) Sustainability indicators for livestock farming. A review. Agron. Sustain. Dev 33: 311-327

Nevedi (2009) De Nederlandse Vereniging Diervoederindustrie. The Dutch Feed Industry Association. Lineaire programmeringen rundvee-, varkens en pluimveevoerders. Linear Programming Cattle-, Pig, and Poultry Feed. Schothorst Feed Research B.V., Lelystad

Nevedi (2010) De Nederlandse Vereniging Diervoederindustrie. The Dutch Feed Industry Association. Lineaire programmeringen rundvee-, varkens en pluimveevoerders. Linear Programming Cattle-, Pig, and Poultry Feed. Schothorst Feed Research B.V., Lelystad

Nevedi (2011) De Nederlandse Vereniging Diervoederindustrie. The Dutch Feed Industry Association. Lineaire programmeringen rundvee-, varkens en pluimveevoerders. Linear Programming Cattle-, Pig, and Poultry Feed. Schothorst Feed Research B.V., Lelystad

CVB (2010) Tabellenboek veevoeding. CVB-reeks nr. 49. Productschap Diervoeder. Centraal Veevoederbureau, Den Haag

Röös E, Sundberg C, Tidåker P, Strid I, Hansson P-A (2013) Can carbon footprint serve as an indicator of the environmental impact of meat production? Ecological Indicators 24: 573-581

Sonnemann G, Castells F, Schuhmacher M (2003) Integrated Life-cycle and Risk Assessment for Industrial Processes (Advanced Methods in Resource and Waste Management Series). Lewis Publishers, Boca Raton

SPSS (2011) Statistical Package for Social Sciences. SPSS Software Package 20.0 for Microsoft Windows, Chicago

Thomassen, MA, de Boer, IJM (2005) Evaluation of indicators to assess the environmental impact of dairy production systems. Agriculture Ecosystems & Environment 111: 185–199

Yan MJ, Humphreys J, Holden MN (2011) An evaluation of life cycle assessment of European milk production. J Environ Manage 92: 372-379

This paper is from:

Proceedings of the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector

LCA Food 2014

8-10 October 2014 - San Francisco

Rita Schenck and Douglas Huizenga, Editors
American Center for Life Cycle Assessment

The full proceedings document can be found here:
http://lcacenter.org/lcafood2014/proceedings/LCA_Food_2014_Proceedings.pdf

It should be cited as:

Schenck, R., Huizenga, D. (Eds.), 2014. Proceedings of the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector (LCA Food 2014), 8-10 October 2014, San Francisco, USA. ACLCA, Vashon, WA, USA.

Questions and comments can be addressed to: staff@lcacenter.org

ISBN: 978-0-9882145-7-6