Org. Agr.
DOI 10.1007/s13165-014-0084-0

# Carbon footprints of organic dairying in six European countries—real farm data analysis

**Sanna Hietala · Laurence Smith · Marie T. Knudsen · Sirpa Kurppa · Susanne Padel · John E. Hermansen**

Received: 27 May 2014 / Accepted: 17 October 2014

**Abstract** Dairy farming is the largest agricultural contributor to greenhouse gas emissions in Europe. In this study, the carbon footprint of organic dairying was evaluated by means of a life cycle assessment, based on real farm data from six European countries: Austria, Belgium, Denmark, Finland, Italy and United Kingdom. A total of 34 farms were analysed. The assessment was carried out using an attributional approach with system boundaries from cradle to farm gate. In relation to dairy production, a functional unit of 1 kg of energy corrected milk was used. The results gave an average of 1.32 kg $CO_2$ equivalents per kilogramme of energy-corrected milk with standard deviation of 0.22, which is consistent with recent studies. The main contributor to this is enteric fermentation from producing animals, resulting in 45 % of total GHG emissions, which is also consistent with previous studies.

**Keywords** Organic milk · Dairy · Carbon footprint · GHG · LCA

## Introduction

Greenhouse gas (GHG) emissions have been of great environmental concern for some time and have provided a focus for life cycle assessment (LCA) studies worldwide. Of all anthropogenic GHG emissions, 18 % is estimated to originate in agriculture (Steinfeld et al. 2006). The largest agricultural contributor to global GHG emissions is cattle farming.

Life cycle assessment methodology has been developed to estimate the product's environmental impacts of its whole life cycle. LCA is an ISO standardised environmental assessment method (ISO 2006a, b). By this standardisation, more comparable results for environmental impact estimation can be achieved. In LCA, several impact categories can be included, one being climate change. Agricultural GHG-related emissions considered in LCA consist of methane ($CH_4$), nitrous oxides ($N_2O$) and carbon dioxide ($CO_2$) from primary and secondary sources. Non-$CO_2$ emissions are converted to $CO_2$ equivalents using standardised characterisation factors to provide a comparable single number result per chosen functional unit. LCA can provide information about emission origins and inefficient resource use and can be used to design mitigation

S. Hietala (✉)
MTT Agrifood Research Finland, Biotechnology and Food Research, University of Oulu,
90014 Oulu, Finland
e-mail: sanna.hietala@mtt.fi

L. Smith · S. Padel
The Organic Research Centre,
Hamstead Marshall, Berkshire RG20 0HR, UK

M. T. Knudsen · J. E. Hermansen
Deparment of Agroecology, Aarhus University,
P.O. Box 50, 8830 Tjele, Denmark

S. Kurppa
MTT Agrifood Research Finland, Biotechnology and Food Research,
31600 Jokioinen, Finland

strategies, but depends highly on quality of the data and inventory at hand (Finnveden et al. 2009).

According to LCA-based analysis by Gerber et al. (2013), global cattle farming contributes an annual total of 4.6 gigatonnes of $CO_2$ equivalents, of which dairy cattle contribute 2.1 gigatonnes of $CO_2$ equivalents a year. When this is allocated to products, milk production contributes a total of 1.4 gigatonnes in $CO_2$ equivalents. In their research, Lesschen et al. (2011) evaluated the GHG emissions of the European livestock sectors, estimating that the highest emissions originated in the dairy sector, with 0.195 gigatonnes $CO_2$ equivalents per year.

Previous studies have shown $CH_4$ from enteric fermentation to have a large impact on GHG emissions in cattle farming. Steinfeld et al. (2006) estimated that of all anthropogenic methane emissions, the agricultural share is 37 % and comes mainly from enteric fermentation of ruminants. Nitrous oxide emissions are estimated even higher, 65 % of all emissions, resourcing mainly from manure.

Few studies (e.g. Henriksson et al. 2011; Kristensen et al. 2011) have evaluated the GHG emissions related to milk production based on real farm data, and in particular, organic systems are under-researched. Earlier, LCA studies on organic dairy farming have assessed the impacts of one specific country per se (Thomassen et al. 2008; Kristensen et al. 2011; De Boer 2003; Cederberg and Mattsson 2000). So far, the only cross-national research in this field is by Guerci et al. (2013), but they included only few organic farms in their study. Typically, organic dairy systems are more diverse, more complex, and rely more on on-farm resources than conventional farming and for, e.g. feed is often homegrown and fertilised using manure from livestock. According to the European Regulations for organic food (European Communities 834/2007), organic dairy cows should be fed mainly on homegrown forages from grass clover leys, permanent pasture and other suitable forage crops (at least 60 % of the ration dry matter must be provided by forages), supplemented by organic straights or concentrates. Of the diet, 100 % must be from organic sources and animals must have access to pasture and lower indoor stocking rates, providing some benefits for animal welfare.

The aim of this study is to identify emission hotspots in organic farms in six European countries based on real farm data by using a LCA approach. The results can then be implemented into suggestions for GHG abatement strategies. In this paper, we have focused on organic dairying and included a wide array of organic farms.

## Materials and methods

We used a LCA approach to assess the carbon footprint of organic dairy farming in six European countries.

### Data collection

The data was collected using public goods (PG) tool developed at the Organic Research Centre with funding from Natural England/Defra, after some modifications to make it more suitable for use in this task. The PG tool assesses each individual farm across 11 "spurs": Soil Management, Biodiversity, Landscape and Heritage, Water Management, Nutrient Management, Energy and Carbon, Food Security, Agricultural Systems Diversity, Social Capital, Farm Business Resilience, and Animal Health and Welfare. The tool is constructed as a spreadsheet with a worksheet for each spur. It makes use of information which the farmer will already have available (e.g. farm accounts, cropping records, animal health plan) resulting in a radar diagram giving a visual impression of the sustainability of a farm and stronger/weaker areas in approximately 2–4 h. For more information on the tool, please see Gerrard et al. (2012), Smith et al. (2011) and Marchand et al. (2014).

Results from the data collections carried out were sent to the Organic Research Centre for central data processing. The spreadsheets were then returned to the research partners, with summaries of the data collected and the results for each country.

### Selection of the case study farms

In this study, we focused on data from a total of 34 organic farms from six European countries participating in the SOLID project. SOLID is a EU-funded project on Sustainable Organic and Low Input Dairying financed by the European Union with 25 partners (several of them SMEs in organic or low-input dairying) from European countries. This study uses data from eight farms with dairy cows in the United Kingdom, eight in Denmark, seven in Finland, two in Belgium, four in Italy and five in Austria. Data were also recorded on farms keeping dairy goats which are not reported here. The farms recruited were members or suppliers of the SMEs processing and/or marketing organic milk and participating in the project. The aim in recruiting case study farms was to illustrate the range within the organic systems rather than a representative sample in terms of: farm size, intensity of input use (within the "organic/low input" population), commonly used breeds and where appropriate marketing channels and on-farm processing (e.g. milk, cheese), as well as geographical areas where these systems are found (see Leach et al. 2013 for further details of the assessment).

In view of the search for innovative systems and methods, the partners were advised to include some farms with an unusual or innovative component compared with other farms in their region. "Unusual or innovative" was understood as being a different way of thinking or doing things under the specific conditions or in the region, but not necessarily as being limited to the invention of a new product or technology which has never been used before (Dockès et al. 2012). Nicholas et al. (2014) found that innovations perceived as conflicting with the 'naturalness' of the production system and products were strongly rejected by stakeholders of organic dairy supply chains, whereas innovations related to improving animal welfare and improving forage quality in order to be able to reduce the need for purchased concentrate feeds were liked.

Data collection included low-input and organic dairy farms, but only organic farms were included in this assessment. In Austria, the focus was a homogenous group of Alpine farms supplying one specific, very localised co-operative. In all other countries, farms supplying the SME came from a heterogeneous group. In particular, Italian farms covered a very broad diversity of geographical areas and locations. In the UK, the dairy farming population is slightly more concentrated in the Western part, and the selection of farms reflected this and the location of the two SMEs in England and Wales. The Danish farms were members of an organic co-operative in Jutland and in Finland of a small organic dairy company in the East of the country. The Belgian partners studied dairy farms and also goat farms in Flanders and the Netherlands which are not included here (Leach et al. 2013). The small number of farms assessed could only provide an illustration of the different types of farms, rather than providing a representative sample.

### Farm descriptions

The farm size varied from 9 to 480 dairy cows and from annual production volumes of 41 to 4,267 tonnes of ECM per farm and annual milk yield per cow from 2,032 to 8,717 kg ECM. Farm descriptions per country are presented in Table 1. In order to obtain the detailed data necessary to run the carbon footprint model, each real farm data was supplemented by stock numbers using a herd turnover model described in Table 2. Replacement ratio average for all farms was 20 % with standard deviation of 13 %.

### Emission modelling

LCA is a method for environmental assessment of a products' life cycle. LCA of a product can consist of several impact categories. Here, we have focused only on GHG emissions. Emissions were converted to $CO_2$ equivalents using the IPCC 100 year global warming potential with values 25 for methane and 298 for nitrous oxide (Forster et al. 2007).

The carbon footprint was calculated using the LCA method described by Schmidt and Dalgaard (2012a, b). The model is introduced in Dalgaard et al. (2014). Here, we used an attributional approach as it has been recommended for dairy production (IDF 2010). In the attributional approach, emissions are allocated to end products. Model uses an allocation factor of approximately 82 % to the milk (Schmidt and Dalgaard 2012a). System boundaries were set from cradle to farm gate. The carbon footprint was calculated per farm, and the result is given as weighted average.

### Functional unit

In LCA, the impact result is given per functional unit. The functional unit (FU) is a measure of the performance of a main product system observed (Guinée et al. 2002). Milk being the final product of this study, we have used a FU of 1 kg of energy-corrected milk (ECM) as in Sjaunja et al. (1990) to provide the fat and protein-corrected milk yield. ECM is defined as raw milk with 4.10 % fat and 3.30 % protein.

### System boundaries

System boundaries were set at farm gate in all cases, overall system boundaries being from cradle-to-gate.

**Table 1** Description of the range of general attributes of the 34 farms studied

| | Austria | | Belgium | | Denmark | | Finland | | Italy | | United Kingdom | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Attribute [unit] | Min | Max | Min | Max | Min | Max | Min | Max | Min | Max | Min | Max |
| Dairy cows [number] | 10 | 17 | 55 | 101 | 36 | 480 | 9 | 124 | 16 | 73 | 105 | 378 |
| Milk yield per dairy cow [kg ECM] | 2391 | 5080 | 7075 | 7887 | 4627 | 8890 | 6503 | 10,233 | 4458 | 8351 | 4212 | 6819 |
| Time on pasture [%] | 55 | 65 | 55 | 55 | 50 | 65 | 25 | 50 | 25 | 75 | 50 | 65 |
| Imported manure and straw [kg N] | 4 | 37 | 0 | 4496 | 0 | 7570 | 0 | 0 | 0 | 0 | 9 | 3426 |
| Rotational grassland [ha] | 0 | 0 | 5 | 28 | 4 | 207 | 3 | 33 | 6 | 28 | 4 | 249 |
| Permanent grassland [ha] | 13 | 24 | 17 | 21 | 3 | 75 | 0 | 5 | 0 | 13 | 32 | 122 |

Range presented per country

These boundaries rule out the end of the life cycle including market, consumption and processes after the farm gate that are considered to be out of farmers' control and irrelevant when focus is on farm activities. Inputs are traced back to production of raw materials and GHG emission sources in relation to production were included. System boundaries are illustrated in Fig. 1.

**Table 2** Parameters and formulas used in the herd turnover model to transfer the data collected on farm into data that serve as input into the LCA model

| Parameter [unit] | Formula | Data collected on-farm |
|---|---|---|
| Replacement ratio (RR) | *N* culled animals / *N* dairy cows | Number of culled animals and dairy cows |
| Newborn heifers [heads] | 0.5 × Total *N* of calves born | Number of calves born |
| Newborn bulls [heads] | 0.5 × Total *N* of calves born | |
| Deathborn heifers [heads] | 0.05 × Newborn heifers | |
| Deathborn bulls [heads] | 0.05 × Newborn bulls | |
| Fallen dairy cows (excl. calves) [heads] | 0.02 × Total *N* of dairy cows | Number of dairy cows |
| Time from birth of 1st calf to slaughter [months] | 12 × (1 / RR) | |
| Average live weight [kg] | *A* × 0.9 | *A*=weight per slaughtered dairy cow |
| Weight after birth of 1st calf [kg] | *A* × 0.8 | |
| Weight per fallen dairy cow [kg] | *A* × 0.9 | |
| Weight per exported dairy cow [kg] | *A* | |
| Weight per imported dairy cow [kg] | *A* × 0.9 | |
| Heifers (average) [heads] | Same as *N* of dairy cows | Number of dairy cows |
| Fallen heifers [heads] | 0.02 × *N* of total heifers | |
| Age at birth of 1st calf [months] | 27, same for all | |
| Time indoor per heifer [%] | Estimated as same as for dairy cows | Time indoor per dairy cow |
| Average live weight [kg] | Calf weight + 0.5 × Weight before calving | Weight per calf+Calculated weight before calving |
| Weight before birth of 1st calf [kg] | A × 0.8+(Calf weight × 1.7) | |
| Weight per fallen heifer [kg] | 0.8 × Live weight | |
| Weight per exported heifer [kg] | Calf weight+Weight before calving / 2 | |
| Weight per imported heifer [kg] | 0.9 × Live weight | |
| Bull calves [heads] | Same *N* as born | |
| Fallen bull calves [heads] | 0.04 × *N* born | |

*RR* replacement ratio, *A* weight per slaughtered dairy cow, *N* number

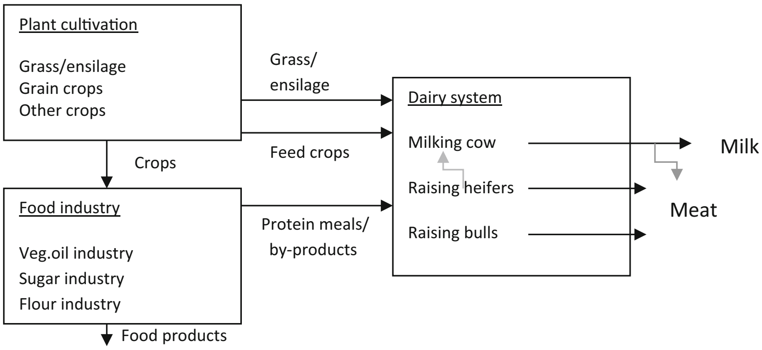


**Fig. 1** Overview of system boundaries as used in this study. Modified from Schmidt and Dalgaard (2012a)

## Inventory data used

The carbon footprint model (Schmidt and Dalgaard 2012a, b) uses detailed inventory data. The model uses inventory data based on literature for the main products of agricultural activities and Ecoinvent database v2.2 data (2007) for other activities. Emissions from capital foods include GHG-emissions from production of machinery, buildings and from services including retail, wholesale and accounting. Inventory data for services was obtained from EU27 input–output database from SimaPro 7.3 in cases where Ecoinvent data was not available (Schmidt 2010; Schmidt et al. 2010).

The parameters included in the model calculation were herd parameters including age and weight, feed characteristics, own production of feed, crop yields, fertiliser use, housing systems including manure management and energy use including traction and air

**Table 3** Average carbon footprint of organic dairying in six European countries per 1 kg ECM

| European average | Dairy cows [kg $CO_2$-eq] | Raising heifers and bulls [kg $CO_2$-eq] | Crop cultivation [kg $CO_2$-eq] | Total [kg $CO_2$-eq] |
|---|---|---|---|---|
| Direct emissions | | | | |
| $CH_4$ enteric fermentation | 0.43 | 0.16 | | |
| $CH_4$ manure handling and storage | 0.07 | 0.02 | | |
| $N_2O$ | 0.03 | 0.01 | 0.25 | |
| Sum of direct emissions | 0.53 | 0.19 | 0.25 | 0.97 |
| Emissions outside animal activities | | | | |
| Feed inputs | | 0.0003 | | |
| Imported feed inputs | | 0.035 | | |
| Manure land application | | 0.002 | | |
| Purchased manure and live animals | | 0.056 | | |
| Fuels | | 0.061 | | |
| Electricity | | 0.066 | | |
| Transport | | 0.005 | | |
| Destruction of fallen cattle | | 0.0000 | | |
| Farm, capital goods and services | | 0.123 | | |
| Sum of emissions outside animal activities | | 0.35 | | |
| Total | | | | 1.32 |

Six European countries involved are Austria, Belgium, Denmark, Finland, Italy and United Kingdom

Direct emissions include $CH_4$ and $N_2O$ from animals, their manure and field emissions. Emissions outside animal activities include upstream emissions from feed production, purchased fertilisers, fuels and combustion, electricity and buildings, etc. $n_{\text{farms}} = 34$

**Table 4** GHG emissions per country

| | AT | | BE | | DK | | FI | | IT | | UK | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Min | Max | Min | Max | Min | Max | Min | Max | Min | Max | Min | Max |
| Emissions as kg $CO_2$ equivalents per kg ECM by country | | | | | | | | | | | | |
| Total | 1.12 | 1.94 | 1.00 | 1.33 | 0.99 | 1.47 | 1.14 | 1.70 | 1.02 | 1.51 | 1.16 | 1.70 |
| Direct emissions from housing, storage and field | | | | | | | | | | | | |
| $CH_4$ enteric fermentation | 0.56 | 0.94 | 0.45 | 0.60 | 0.51 | 0.74 | 0.47 | 0.60 | 0.49 | 0.70 | 0.56 | 0.76 |
| $CH_4$ manure handling and storage | 0.06 | 0.13 | 0.07 | 0.10 | 0.04 | 0.11 | 0.08 | 0.15 | 0.06 | 0.16 | 0.05 | 0.13 |
| $N_2O$ | 0.24 | 0.47 | 0.23 | 0.27 | 0.14 | 0.38 | 0.23 | 0.33 | 0.21 | 0.41 | 0.26 | 0.42 |
| Emissions outside animal activities | | | | | | | | | | | | |
| Imported feed and inputs | 0.00 | 0.05 | 0.04 | 0.07 | 0.00 | 0.12 | 0.00 | 0.09 | 0.02 | 0.06 | 0.01 | 0.06 |
| Fuels and combustion | 0.057 | 0.047 | 0.043 | 0.051 | 0.019 | 0.067 | 0.034 | 0.047 | 0.038 | 0.07 | 0.051 | 0.078 |
| Electricity | 0.03 | 0.14 | 0.03 | 0.09 | 0.02 | 0.08 | 0.04 | 0.14 | 0.04 | 0.06 | 0.00 | 0.08 |
| Other[a] | 0.04 | 0.32 | 0.01 | 0.06 | 0.03 | 0.15 | 0.09 | 0.32 | 0.03 | 0.15 | 0.00 | 0.07 |

Lowest (min) and highest (max) contributors presented

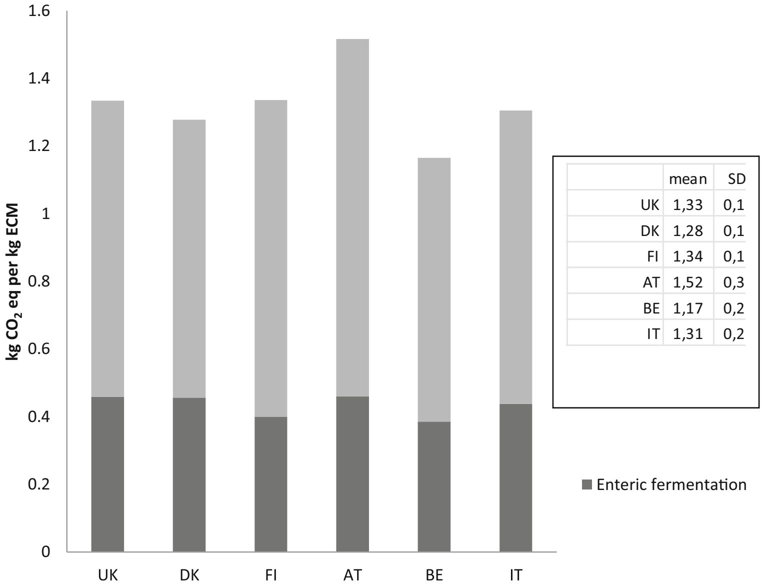
[a] Transport, farm capital goods and services, manure land application and destruction of fallen cattle

conditioning. The calculation model uses the milk yield, weight and ages of the cattle to calculate the feed requirement. Feed requirement is calculated in terms of energy demand which is set to match input milk yield. Energy demand is estimated based on expert interviews for dairy cows and on IPCC (2006) for other cattle. Emissions from cultivation, manure management, enteric fermentation and methane were calculated according to IPCC (2006). Using the attributional approach, emissions were economically allocated between milk, beef and manure according to its energy and nutrient content (Schmidt and Dalgaard 2012a, b).

## Results

Based on real data from six countries and a total of 34 organic dairy farms, the result for the average carbon

**Fig. 2** Carbon footprint averages per country per functional unit, with standard deviation (SD). Enteric fermentation emphasised



| | mean | SD |
|---|---|---|
| UK | 1,33 | 0,1 |
| DK | 1,28 | 0,1 |
| FI | 1,34 | 0,1 |
| AT | 1,52 | 0,3 |
| BE | 1,17 | 0,2 |
| IT | 1,31 | 0,2 |

footprint for 1 kg of energy-corrected organic milk was 1.32 kg $CO_2$ equivalents per kilogramme of ECM with standard deviation of 0.22. Emissions are divided between the processes including direct emissions from animals, manure and cultivation and emissions outside animal activities, including feed inputs, fuels, electricity, transport and farm capital goods and services. Results are presented in Table 3. The distribution of GHG emissions of lowest and highest contributors per country to total average GHG is presented in Table 4. Total carbon footprint is ranging from 0.99 to 1.94 kg $CO_2$ equivalents per kilogramme of ECM. Average GHG emissions by country with standard deviations (SD) are presented in Fig. 2.

Of the total average GHG emissions, from the largest contributor, enteric fermentation by dairy cows contributes 33 % and by raising cattle contributes 12 %. N2O emissions from housing and crop cultivation account for 22 %, farm capital goods account for 9 % and manure management is 6 % of the total emissions. Electricity and fuels are both contributing 5 %, purchased manure and live animals 4 % and imported feeds contribute 3 % of total GHG emissions. Taken together, the above factors contribute 99 % of all included GHG emissions, the remaining 1 % resulting from transport and manure treatment. Of these, the main contributor is enteric fermentation, which accounts for nearly half of all GHG emissions in total.

Of these, the main single activity as contributor is enteric fermentation, which accounts for one third of all GHG emissions in total. Carbon footprints plotted against different farm attributes are presented in Fig. 3.

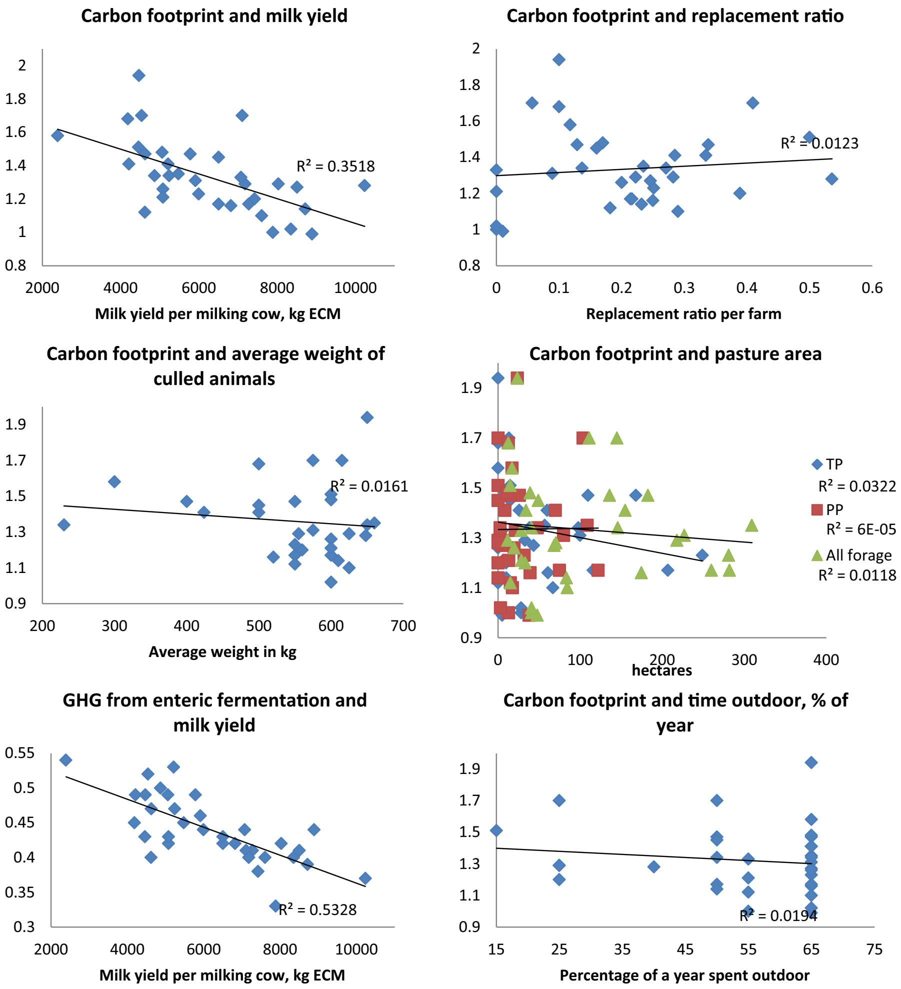


**Fig. 3** Carbon footprint and general attributes of organic dairy farms. Carbon footprint as kilogramme $CO_2$ equivalents per kilogramme ECM on *y*-axis

## Discussion

The current study reveals variations in GHG emissions between dairy-producing farms and between countries. Total GHG emissions varied from 0.99 to 1.94 kg $CO_2$ equivalents per ECM, with mean at 1.32 and standard deviation of 0.22. This result is consistent with recent previous studies, from the perspective of the overall carbon footprint. With ECM or kilogramme milk as a functional unit, previous studies have shown a wide variation of results ranging from average of 1.5 kg CO2 equivalents per FU in both Thomassen et al. (2008) and Casey and Holden (2005), 1.27 in Kristensen et al. (2011) and 1.13 in Flysjö et al. (2012), although methodological and regional variations make a direct comparison difficult.

Here, the enteric fermentation was the largest contributor to the total carbon footprint. Calculation of methane emissions from enteric fermentation depend on assumed gross energy intake (IPCC 2006). Therefore, GHG emissions from enteric fermentation of farms with less energy intake compared to corresponding milk yield are lower. When emissions were viewed against different input attributes, some correlation could be seen with milk yield as ECM and lower GHG emissions (Fig. 3.). Although the sample size is small, large variation in milk yields can be seen. Other attributes are not showing clear correlation, but effects of replacement ratio and pasture use should be investigated further.

Nutritional and genetic attributes should be further studied in order to find mitigation potentials of the lower milk-yielding farms. In the mitigation of GHG emissions from organic dairy sector, feed quality and the nutrient efficiency play a large role. Feed digestibility could be improved, even if it is already considered high in Western Europe, at 77 %, compared to the global average of 60 % (Gerber et al. 2013).

In mitigating N2O emissions, large impact is in manure/fertiliser and land use efficiency. Housing and manure management could also be further developed in a sustainable direction. Adoption of better manure application techniques and increased use of methane gas as biogas would also be of assistance (Weiske et al. 2006; Belflower et al. 2012).

Besides farm activities, the method for calculating the carbon footprint could be improved; this calculation does not yet take account of carbon sequestration—doing so would change the results to the benefit of farms using more grass-based permanent pastures (Yan et al. 2013). Adding carbon sequestration to these calculations would provide a more complete picture of GHG emissions from organic dairy farms. Freibauer et al. (2004) have shown that EU has large potential in agricultural soil carbon sequestration. They point out practices for carbon sequestration, one being organic farming. Generally, grasslands are assumed as carbon sinks and croplands are releasing carbon. From a dairy production point of view, Mogensen et al. (2014) have introduced a method for calculating carbon sequestration of cattle feeds that could be integrated into these calculations.

Agriculture being a large contributor to GHG emissions and cattle farming being the largest agricultural source, mitigation strategies are needed as demand for cattle-based products are constantly growing with expanding population. Gerber et al. (2013) estimated the mitigation potential of the dairy sector in Western Europe to be 11–14 %. Previous studies have shown enteric fermentation in cattle farming to have a large impact on GHG emissions. Variations in the tactical management of farms can be viewed as leading to variances in emissions (Henriksson et al. 2011).

Dairy farming is the largest agricultural contributor to GHG emissions in Europe, and organic milk production is responsible for its proportional share. Thus, also for organic milk production, mitigation strategies need to be adapted. It is important that such mitigation strategies do take into account the other important features of organic dairy production like impact on biodiversity and on changes in soil carbon sequestration. Although enteric fermentation is the largest contributor to GHG emissions, development of more sustainable practises should therefore not only be in feed design but also in overall tactical management on farms. Organic dairy farming can lead by example in this.

**Acknowledgments** Funding from the European Community's Seventh Framework Programme (FP7/ 2007–2013) was received for the research leading to these results, under grant agreement no. FP7-266367 (SOLID-Sustainable Organic and Low Input Dairying). For further details, see www.solidairy.eu.

## References

Belflower JB, Bernard JK, Gattie DK, Hancock DW, Risse LM, Alan Rotz C (2012) A case study of the potential environmental impacts of different dairy production systems in Georgia. Agric Syst 108:84–93

Casey JW, Holden NM (2005) Analysis of greenhouse gas emissions from the average Irish milk production system. Agric Syst 86:97–114

Cederberg C, Mattsson B (2000) Life cycle assessment of milk production—a comparison of conventional and organic farming. J Clean Prod 8:49–60

Dalgaard R, Schmidt J, Flysjö A (2014) Generic model for calculating carbon footprint of milk using four different life cycle assessment modelling approaches. J Clean Prod 73:146–153

De Boer I (2003) Environmental impact assessment of conventional and organic milk production. Livest Prod Sci 80:69–77

Dockès AC, Tisenkopfs T, Bock BB (2012) The concept of agricultural knowledge and innovation systems. Chapter 3 In EU SCAR-(2012), p 23–39

Ecoinvent (2007) Ecoinvent data v2.2. Final reports Ecoinvent v2.2 No. 1–25. Swiss Centre for Life Cycle Inventories, Dübendorf

European Communities (2007) Council Regulation (EC) No. 834/2007 of 28 June 2007 on organic production and labelling of organic products and repealing Regulation (EEC) No 2092/91. Off J Eur Commun 20.7.2007. Brussels. L189/1, 1–23

Finnveden G, Hauschild MZ, Ekvall T, Guinee JB, Heijungs R, Hellweg S, Koehler A, Pennington D, Suh S (2009) Recent developments in life cycle assessment. J Environ Manage 91:1–21

Flysjö A, Cederberg C, Henriksson M, Ledgard S (2012) The interaction between milk and beef production and emissions from land use change—critical considerations in life cycle assessment and carbon footprint studies of milk. J Clean Prod 28:134–142

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. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds) Climate Change 2007: the physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge

Freibauer A, Rounsevell MD, Smith P, Verhagen J (2004) Carbon sequestration in the agricultural soils of Europe. Geoderma 122(1):1–23

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 (FAO), Rome

Gerrard CL, Smith LG, Pearce B, Padel S, Hitchings R, Measures M, Cooper N (2012) In: Lichtfouse E (ed) Public goods and farming for food and water security. Springer, Netherlands, pp 1–22

Guerci M, Knudsen MT, Bava L, Zucali M, Schönbach P, Kristensen T (2013) Parameters affecting the environmental impact of a range of dairy farming systems in Denmark, Germany and Italy. J Clean Prod 54:133–141

Guinée JB, Gorrée M, Heijungs R, Huppes G, Kleijn R, Koning A, de Oers L, van Wegener Sleeswijk A, Suh S, Udo de Haes HA, de Bruijn H, van Duin R, Huijbregts MAJ, Lindeijer E, Roorda AAH, van der Ven BI, Weidema BP (eds) (2002) Handbook on life cycle assessment. Operational guide to the ISO standards. Centrum voor Milieukunde – Universiteit Leiden (CML). Kluwer Academic Publishers

Henriksson M, Flysjö A, Cederberg C, Swensson C (2011) Variation in carbon footprint of milk due to management differencies between Swedish dairy farms. Animal 1–11

IDF (2010) A common guide for carbon footprint approach for dairy. The IDF guide to standard life cycle assessment methodology for the dairy sector. The international Dairy Federation

International Panel on Climate Change (2006) Guidelines for national greenhouse gas inventories. IPCC, Geneva. Available at: http://www.ipcc-nggip.iges.or.jp

ISO (2006a) Environmental management—life cycle assessment—principles and framework. ISO 14040:2006(E). International Organization for Standardization, Geneva

ISO (2006b) Environmental management—life cycle assessment—requirements and guidelines. ISO 14044:2006(E). International Organization for Standardization, Geneva

Kristensen T, Mogensen L, Knudsen MT, Hermansen JE (2011) Effect of production system and farming strategy on greenhouse gas emissions from commercial dairy farms in a life cycle approach. Livest Sci 140:136–148

Leach K, Gerrard CL, Padel S (eds) (2013) Rapid sustainability assessment of organic and low-input farming across Europe and identification of research needs. Deliverable 1.1, EU-SOLID project. ORC, Hamstead Marshall, Newbury. Available online: http://orgprints.org/22721/

Lesschen JP, van der Berg M, Westhoek HJ, Witzke HP, Oenema O (2011) Greenhouse gas emission profiles of European livestock sectors. Anim Feed Sci Technol 166–167:16–28

Marchand F, Debruyne L, Triste L, Gerrard C, Padel S, Lauwers L (2014) Key characteristics for tool choice in indicator-based sustainability assessment at farm level. Ecol Soc 19:3

Mogensen L, Kristensen T, Nguyen TLT, Knudsen MT, Hermansen JE (2014) Method for calculating carbon footprint of cattle feeds—including contribution from soil carbon changes and use of cattle manure. J Clean Prod 73:40–51

Nicholas PK, Mandolesi S, Naspetti S, Zanoli R (2014) Innovations in low input and organic dairy supply chains—what is acceptable in Europe? J Dairy Sci 97(2):1157–1167

Schmidt J (2010) Contribution analysis, uncertainty assessment, and policy recommendation. Deliverable 6-3 of the EU FP6-project FORWAST

Schmidt JH, Dalgaard R (2012a) National and farm level carbon footprint of milk—methodology and results for Danish and Swedish milk 2005 at farm gate. Arla Foods, Aarhus

Schmidt JH, Dalgaard R (2012b) National and farm level carbon footprint of milk—life cycle inventory fro Danish and Swedish milk. Arla Foods, Aarhus

Schmidt J, Weidema B, Suh S (2010) Documentation of the final model used for the scenario analyses. Deliverable 6-4 of the EU FP6-project FORWAST

Sjaunja LO, Baevre L, Junkkarinen L, Pedersen J, Setälä J (1990) A Nordic proposal for an energy corrected milk (ECM) formula. 27th session. ICRPMA, Paris

Smith LG, Padel S, Pearce B, Lampkin N, Gerrard C, Woodward L, Fowler S, Measures M (2011) Assessing the public goods provided by organic agriculture: lessons learned from practice. In: Neuhoff D, Halberg N, Rasmussen IA, Hermansen J, Ssekyewa C, Mok S (eds) The third scientific conference of

ISOFAR: organic is life—knowledge for tomorrow, Namyangju, Republic of Korea, pp 59–63

Steinfeld H, Gerber P, Wassenaar T, Castel V, Rosales M, De Haan C (2006) Livestock's long shadow. FAO, Rome

Thomassen MA, van Calker KJ, Smits MCJ, Iepema GL, de Boer IJM (2008) Life cycle assessment of conventional and organic milk production in the Netherlands. Agric Syst 96:95–107

Weiske A, Vabitsch A, Olesen JE, Schelde K, Michel J, Friedrich R, Kaltschmitt M (2006) Mitigation of greenhouse gas emissions in European conventional and organic dairy farming. Agric Ecosyst Environ 112:221–232

Yan MJ, Humphreys J, Holden NM (2013) The carbon footprint of pasture-based milk production: can white clover make a difference? J Dairy Sci 96:857–865