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Greenhouse gas emissions of packaged fluid milk production in Tehran

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ABSTRACT

The main purpose of this study was first to estimate the carbon footprint (CF) of packaged fluid milk through life cycle assessment (LCA), using regional data in Tehran, and then to identify opportunities for lower greenhouse gas (GHG) emissions. The system boundary for cradle to gate assessment was divided into three life cycle stages: agronomy, animal farm and dairy plant, and data were gathered from multiple sources, e.g. questionnaire, published studies and dairy plant database in 2011–2012. Through the study, the IPCC 2006 methodology and the International Dairy Federation (IDF) Carbon Footprint Guide were used to calculate the CF of milk. The functional unit (FU) was one litre of pasteurized milk packaged in a plastic pouch. The average CF for 1 kg of fat-protein corrected milk (FPCM) at the farm gate was 1.57 kg CO_2-eq, however, for the FU, it was 1.73 kg CO_2-eq. The main contributors to overall CF of milk product were enteric methane 30%, electricity 14%, diesel 8.9%, manure emissions 8.8% and transportations 8.6%. The average CF of FPCM at farm gate was higher than the previous European reports, but lower than the previous estimate of 3–5 kg CO_2-eq/kg milk. Developing the infrastructure to utilize renewable energy sources, such as solar energy, may be a solution for high share of energy-related emissions from the dairy sector. We call for more research on CF and other environmental impacts like eutrophication, and impacts from water consumption in different regions of the country both in traditional and industrial dairy farm systems.

1. Introduction

Greenhouse gas (GHG) emissions in dairy sector of developing countries need to be studied for three main reasons. First, dairy sector will be one of the fastest-growing agricultural sub-sectors in developing countries in the coming decades (Gerosa and Skoet, 2013). Second, management practices, soil characteristics, climate, animal performance and other factors that affect GHG emissions differ significantly between regions. Third, reporting national greenhouse gas inventories is becoming a standard practice in governments.

Consumption of resources and emissions to the environment occur at all stages in a dairy product's life cycle, that is, from growing feed to the final packaging. The dairy industry in Iran usually comprises three distinct life cycle (LC) stages: agronomy, milk production and dairy processing. Iran produces about 1.4% of the world's cow milk, which corresponds to 8.405 million tons per year, of which 54% is produced in industrial dairy farms and delivered to dairy processing plants (IDF, 2011). According to a recent report, Iran ranks 18th in the world in greenhouse gas (GHG) emissions, but 58th in per capita emissions (WRI, 2013).

Life-cycle assessment (LCA) is one of the methods used to assess the environmental impact of a product throughout the product chain (ISO, 2006). An LCA that is limited to addressing the contribution to climate change is usually called a carbon footprint (CF) or climate change impact assessment. The CF refers to the sum of GHG emissions caused by an organization or a product and is expressed in terms of CO_2 equivalents (CO_2-eq) (Cederberg et al., 2013).

Dairy production, along with all other types of animal agriculture, is a recognized source of GHG emissions (Rotz et al., 2010)

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and dairy products' CF has been assessed frequently, for instance, in fluid milk (Thoma et al., 2013) and cheese (González-García et al., 2013; Kim et al., 2013). Typically, studies in various dairy systems do not assess the complete life cycle of a dairy product. Instead, the effect of animal farm system on the environment is evaluated up to the point the raw milk is sold by the farm. Until now, many studies have estimated the CF of raw milk in conventional pasture-based systems (Guerci et al., 2013), confinement-based systems (O'Brien et al., 2012) and on organic farms (Guerci et al., 2013; Schader et al., 2013). However, in these studies the main focus was on European dairy systems or on other temperate regions such as New Zealand (Basset-Mens et al., 2009), and so there is limited information available about the situation in arid regions.

One study in Spain found that in the production of UHT pasteurized milk about 80% of CF was from the raw milk production at farms and about 20% was from the processing stage in the dairy plant (Hospido et al., 2003). Many dairy farms have reported CF values between 1 and 1.4 kg CO_2-eq per kg raw milk. In Ireland, for instance, a study concluded that an average dairy unit emitted 1.3 kg CO_2-eq per kg raw milk, and from total emissions, 49% was from enteric fermentation, 21% from fertilizer, 13% from concentrate feed, 11% from dung management and 5% from electricity and diesel consumption (Casey and Holden, 2005).

Agricultural production is usually associated with three GHGs, carbon dioxide, methane and nitrous oxide (Więk and Tkacz, 2013). For all livestock products, CO_2 appeared to be the least important greenhouse gas and emission of CO_2 seemed to be directly related to the combustion of fossil fuels (De Vries and De Boer, 2010). Various processes in milk's life cycle produce other two potent GHGs (i.e. methane and nitrous oxide). Fertilizer use and manure production are the main sources for direct N_2O, and indirect N_2O can be produced from ammonia volatilization, nitrite/nitrate leaching and runoff. Methane is emitted mainly from enteric fermentation in animal farm and usually contributes most to the CF of milk (Cederberg and Mattsson, 2000).

Generally, higher feed gross energy intake by cow will cause higher enteric methane emissions, although the composition of the diet also plays an important role (IPCC, 2006). Methane is also emitted from anaerobic reactions of manure's carbon content. However, this mainly depends on two factors: volatile solids excreted in manure and type of manure management system. The amount of manure volatile solids can be estimated based on feed intake and feed digestibility. Feed characteristics can be uncertain because of the large variations between individual feeds, depending on the place of origin, transportation, storage and cropping practices (Abbasi et al., 2008).

The methods used to allocate emissions between each feed item and particular co-products, between milk and beef, or among various dairy products can significantly influence the overall results. Cederberg and Stadig (2003) showed that depending on the allocation method used between beef/milk, which was between 63 and 92% to milk, GHG emissions ranged from about 0.67 to 1.06 kg CO_2-eq for producing 1 kg milk at the farm. Also, various assumptions, exclusions and methods used in the assessment of a product may cause different results. To reduce confusion in dairy products' CF studies, in 2010, the International Dairy Federation (IDF) published its guideline for common carbon footprint methodology in the dairy sector.

The objectives for this investigation were to quantify the CF in the life cycle of packaged milk and then to identify hotspots in the product system studied and, finally, identify opportunities for overall impact reduction. The present study was the first attempt to assess an environmental impact category in the life cycle of a dairy product in Iran.

2. Methods

2.1. Life-cycle assessment

The life cycle analysis was performed in compliance with the ISO 14040:2006, 14044:2006 standards and the IDF guideline on carbon footprinting (IDF, 2010). The stages of LCA methodology included were goal and scope definition, inventory analysis (LCI), impact assessment (LCIA) and interpretation of results (ISO, 2006). The study was a cradle-to-milk processing gate, attributional life cycle, carbon footprint assessment done for about one year, between 2011 and 2012. To manage data and for graphical illustrations, Simapro v7.3 and Ms. Excel were used depending on the needs.

2.2. Goal and scope

The goal for this study was to develop an LCA model to study CF from the production of packaged milk in Tehran, which may aid in environmentally conscious decision-making. The scope included three separate LC stages. The first stage was the agronomy and supporting background processes, in which feed for the cows is produced. The second was the milk production, where milk is produced, and the third LC stage was the dairy processing in which various dairy products are produced and packaged. Fig. 1 presents the system boundary in this study. It can be seen that the activities of consumer related to purchase and consuming, such as transport, cooling, preparation, spillage and final disposal of packaging are not included due to lack of data and large variation.

2.3. Functional units

Functional units (FU) describe the primary function fulfilled by a product system. In this study, the FU was one litre of medium-fat (2.5% fat; 11% milk solids) pasteurized milk, packaged in a 3-layer low-density polyethylene (LDPE) film pouch at the milk processing gate, ready for use by consumers. Because of the importance of the milk production stage on overall results, many studies deal solely with milk production to the farm gate. Hence, we decided to calculate CF of milk at the farm gate, because it could give us the possibility of comparing our results with other studies. We considered the milk at farm gate as reference flow (RF), and it corresponded to 1 kg of fat-protein corrected milk (FPCM) with 3.3% protein and 4% fat (standard milk). For this aim, the raw milk weights with the various fat and protein contents were converted to FPCM using the formula suggested by the IDF (Gerber et al., 2010).

$$\mathrm{FPCM(kg)} = \mathrm{raw\ milk(kg)} * (0.337 + 0.116 * \mathrm{fat\ content}(\%) + 0.06 * \mathrm{protein\ content}(\%)) \quad (1)$$

2.4. System boundary

The region of Tehran had a population of 14.6 million in 2011. The total farming area was about 201,602 ha, and of that 52,000 ha (25.7%) were under forage crop farming. In addition, this region produced 7.5% of the country's cow milk in 2011 (SCI, 2012).

2.4.1. Agronomy stage

Recently published regional studies were used to obtain the inputs of resources and energy and yield output for corn silage (Pishgar Komleh et al., 2011), alfalfa (Mobtaker et al., 2012), barley (Azarpour, 2012), wheat (Shahan et al., 2008), sugar beet pulp

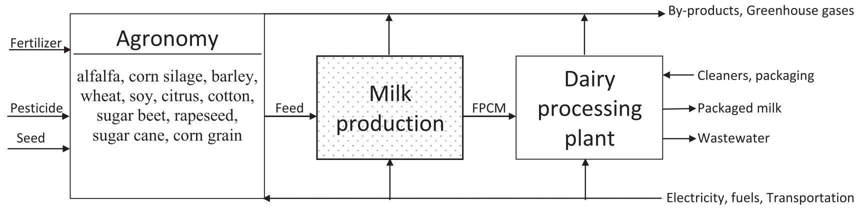

Fig. 1. Scope and system under study.

(Bazrgar et al., 2011) and citrus pulp (Namdari et al., 2011). These feed items accounted for more than 70% of dry matter in the rations. To calculate the inventory of other constituents of the rations, Ecoinvent v.2 processes were used because Iran is a heavy importer of feed items, notably soy meal and corn grain from countries like Brazil, the USA, Russia and India. Because of lack of national data, for other feed items (rape meal, cottonseed meal and sugar cane pulp), modified Ecoinvent v.2 processes (e.g. electricity mix and transportation) were created and used (Ecoinvent, 2010). Import and export information about feeds and their country of origin, and about other agricultural commodities (e.g. fertilizers) was taken from statistical reports of the Ministry of Agriculture (2010) and the Tehran Chamber of Commerce (TCCIM, 2012). In 2011, about 62% of fertilizers needed were produced by Iranian manufacturers; however, nearly all the triple super phosphate fertilizer was imported.

2.4.2. Milk production stage

We selected seven dairy farms out of more than 50 that were providing milk to the dairy plant, depending on their cooperation. All the dairy farms were feedlot units with no grazing in pasture. In the most cases, the farmers did not participate in agronomy operations on their own farms and obtained feed constituents from other farmers. The seven animal farms selected were industrial farms with milking system, tractors, veterinarians and feed grinders. Each herd was classified into six classes of milking cow, dry cow, heifer, beef cattle, 6–12 months and under 6 months. The data were collected by a face-to-face questionnaire in 2012. The questionnaire included questions about herd composition and average rations in each group, origin of feed items, milk weight (kg/day) and fat-protein content (%), beef (live weight) sold, manure sold (m^3/year), manure management, milk transportation distance (km), electricity (kWh), diesel (L), replacement rate (%) and common management practices. In the dairy farms studied, the dairy cows were Holsteins, the most common dairy breed with an adult weight of 600–650 kg/head. The major outputs of the dairy farms were milk, animal live weight (beef) and manure. The beef output included surplus calves and culled milking cows. The average replacement rate of culled cows with new heifers was 20–25%. The main uses of electricity on the farms were for pumping water from wells, cooling animals in warm seasons using water spraying and ventilation, milking, and grinding grain to prepare the mixed rations.

2.4.3. Dairy processing stage

For the dairy processing stage, Pegah-Tehran with 600 tons/day capacity of milk processing was selected as a pilot plant. The refrigerated raw milk was delivered to the dairy plant directly from the farms or from milk collection centres by insulated tankers. After the common high-temperature, short-time (HTST) pasteurization process, the milk was packaged in six grams of LDPE film, and was ready for distribution to retailers. Required input–output data of 2011–2012 were collected from an internal database of the processing plant.

2.5. Allocation and exclusion

In the feed production stage, the allocations between each feed item and associated co-products were done for regional studies (not ecoinvent) based on economical method using two-year average price in Iranian market (Ministry of Agriculture, 2010), and the calculated allocation factors were corn silage 100%, alfalfa 100%, barley 70%, wheat straw 15%, sugar beet pulp 10% and citrus pulp 17%. For dairy farms, we used the bio-physical allocation proposed by the IDF (2010) to allocate the environmental burden between beef (live weight) and milk. This method is based on an energy requirements formula for biologically producing milk and animal live weight. In dairy plants, many products are normally manufactured each day. In this case, the allocations were done based on the milk solid method suggested by Feitz et al. (2007). Milk processors may also use the milk solid content of a product as a basis for price determination.

System expansion was used to deal with the manure exported from the system because manure reduced the need for fertilizers in other agricultural product systems; hence, it reduced the amount of emissions and resources from those systems. Moreover, it also had economic value for the dairy farms. The equivalency factors used to convert manure to synthetic fertilizers were 5 kg N, 2.3 kg P_2O_5 and 5 kg K_2O per ton of the manure managed in solid storage and sold to other farmers for horticulture and gardening (Pennington et al., 2009; Pouryousef et al., 2010).

Exclusions from the model were human labour, infrastructure, machinery and maintenance, and generally, cut-off criteria were set at 5%. In agronomy, important exclusions were microelement fertilizers like Fe, Zn and Mg. Carbon sequestration in soil was also excluded, not only because of lack of reliable studies but also because most of the arable lands were under cultivation for more than 20 years, and so, according to the IPCC, might be in equilibrium.

On dairy farms, cleaning agents, the animal's vitamins supplement, medications and refrigerants were not considered in the inventory collection because of the lack of data and their minor contribution to the overall impact. Bedding materials were not included; according to the IPCC (2006), since all the manures were managed under solid storage systems, their contribution would not have added significantly to overall GHG emission.

Of all the cleaning agents used at the dairy plant, we only considered acid (nitric acid) and alkaline (sodium hydroxide) cleaners because of their dominant quantity. Moreover, the yearly loss of cooling agent from the ice bank, in this case liquid ammonia, was not included in our data collection because it does not contribute significantly to the CF.

2.6. Life-cycle inventory

Emissions from the production and use of energy carriers can be an important part of the overall burden. To calculate GHG emissions from the Iranian electricity production mix based on kWh, we used the 2010 report of the Iran Power Generation, Transmission &

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Distribution Management Company (TAVANIR) to calculate CO_2, CH_4 and N_2O quantities from fuel combustion in power plants according to the IPCC methodology (Tavanir, 2011). The grid loss was considered 15% (Worldbank, 2010). However, we used Ecoinvent v.2 processes for renewable power generation, for example, wind or hydropower.

For calculating the emissions related to diesel use in agriculture and on farms mainly by tractors and natural gas in boilers of the dairy plant, we used the IPCC (2006) method for estimating GHG emissions based on heating value and specific gravity of the fuel used. Emissions from extraction, piping and refining were taken from Ecoinvent v.2 (Ecoinvent, 2010). Average Iranian diesel characteristics used were 42.2 MJ/kg with a density of 0.84 kg per litre (NIOPDC, 2013). The energy value of natural gas was 35.53 MJ/m^3, and assumed fuel oil density was 0.92 kg/l (Zabihian and Fung, 2010).

In the agronomy LC stage, the IPCC (2006) methodology was used to estimate both direct and indirect emissions. According to the IPCC, direct nitrous oxide emission is about 1% of the total nitrogen added to the soil. To estimate indirect nitrous oxide emission from volatile N loss in cropland, the first 0.1 of the total added N to the soil was calculated and then 0.01 of this volatilized N assumed to be converted to nitrous oxide. Because all the feed items were from irrigated arable lands, the IPCC default coefficients were used for leaching/runoff estimations. That is, the first 30% of N added to the land was calculated as the amount that left the system by leaching/runoff and then 0.75% of that amount was considered as having oxidized to $N-N_2O$.

Enteric methane emissions were calculated according to the IPCC tier 2 methodology, based on feed energy intake by animal. The energy content of each feed item was taken from the Iranian Tables of Feed Compositions (ITFC), which contains the results of previous composition studies on more than 80 feed items, including dry weight, gross energy, crude protein, crude fibre, neutral detergent fibre and ash, among others (Abbasi et al., 2008). After consulting with animal science experts, a conversion factor of 5.5% was selected for enteric methane emissions.

In all the farms studied, manure was managed in solid storage, which means it was piled in an unconfined area until the proper season to use it in crop production. To estimate methane emitted from manure, the IPCC 2006 tier 2 method was used. To calculate volatile solid excretion in manure, we assumed an average feed digestibility of 65% for all the farms as reported in previous studies (Bohluli et al., 2009; Moeini et al., 2010). The coefficients of maximum methane production (B_o) and methane conversion factor (mcf) were 0.24 and 0.04, respectively.

To account for nitrous oxide emission from the dairy farms, the nitrogen balance of each farm was calculated separately. In the first step, the daily nitrogen excretion for each farm was calculated as the difference between nitrogen intake from rations and N retained as animal products of milk (protein content was 3.1–3.3%), and beef (28 g N/kg live weight) (Cottrill and Smith, 2007). The crude protein content of rations was calculated from the ITFC national database (Abbasi et al., 2008). To calculate direct emissions from the farms, we assumed that 0.5% of N deposited in manure was emitted as N_2O. Indirect N_2O following re-deposition of NH_3 to soil and water was calculated by first, considering 30% rate of volatile loss of the excreted N and then, 1% of the total $N-NH_3$ as $N-N_2O$. The calculations of nitrous oxide emission from nitrate runoff and leaching were done by considering a 3% and 4% loss of total N from runoff and leaching, respectively. Then 0.75% of these runoff/leached N, calculated as indirect $N-N_2O$ emissions from the dairy farms (IPCC, 2006). Urea applied as a fertilizer also emits CO_2. Of the applied urea, 0.2 kg/kg is carbon by weight that will eventually oxidize to CO_2.

In the milk product chain, we needed to use estimates in many situations. To present the uncertainty inherent to CF estimations at the farm gate, we applied worst-case and best-case scenarios by first choosing the highest emission factors related to fossil fuel use, emissions from manure (methane and nitrous oxide) and fertilizer use, and then calculating the CF per FPCM for each farm. Then the best-case scenario was calculated by choosing the lowest emission factors from the suggested ranges.

2.7. Life-cycle impact assessment

The carbon footprint assessment was done according to the model and methodology developed by the IPCC (IPCC, 2006). All the GHGs aggregate into one indicator that is CO_2-eq. The characterization factors for a 100-year horizon were 1, 25 and 298 for carbon dioxide, methane and nitrous oxide, respectively (Solomon et al., 2007). The normalization step was performed by calculating the GHG emissions from the production and processing of 35 kg of fluid milk for each Iranian per year, as reported by the IDF (2011), and then dividing it by the total GHG emissions of 9760 kg CO_2-eq/year for an average person in Iran (WRI, 2010).

3. Results

On average, each kilogram of FPCM in this study had CF of 1.57 kg CO_2-eq at farm gate, which, when compared to 1.73 kg CO_2-eq per each FU at the milk processing gate, it shows that about 90% of the CF/FU is from the raw milk production. Contributions of each stage to the overall CF/FU were agronomy 43%, milk production 48% and dairy plant 9% (Fig. 2). In addition, for the three main GHGs, our result showed that carbon dioxide 41%, methane 39% and nitrous oxide 20% contributed to the overall CO_2-eq per kilogram FPCM (Fig. 3). The GHGs proportion in this study is different from some previous reports of raw milk where methane had the highest share (De Vries and De Boer, 2010; Mc Geough et al., 2012).

Electricity production in Iran relies heavily on fossil fuels, especially natural gas. In 2011, about 4% of net electricity (kWh) production was from renewable sources (Tavanir, 2011). The total emission was 0.77 kg CO_2-eq per kWh, although after considering a 15% loss in grid (Worldbank, 2010), it became 0.91 kg CO_2-eq per kWh at consumers. Overall, 0.24 kg CO_2-eq/FU (packaged milk) was emitted to provide electricity for the production and processing of milk. Electricity accounted for about 14% of CF in the product chain from the cradle to the milk processing gate. Transportation including transport of feed to farms and of raw milk to the dairy plant contributed about 9% to the overall life cycle GHG emissions. Combustion of one litre of diesel resulted in the formation of 2.65 kg CO_2, 0.35 g CH_4 and 0.021 g N_2O or, in total, 2.665 kg CO_2-eq.

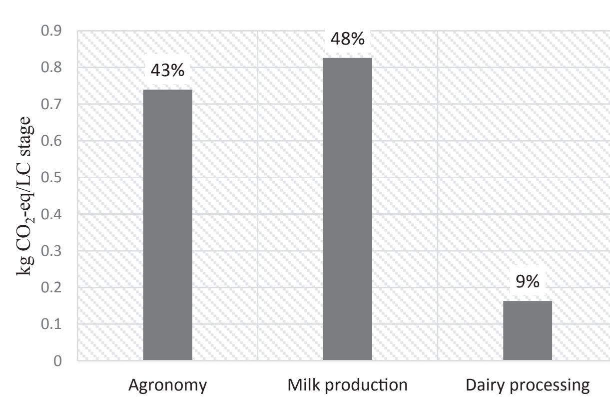

Fig. 2. Contribution of each LC stage to overall CF/FU.

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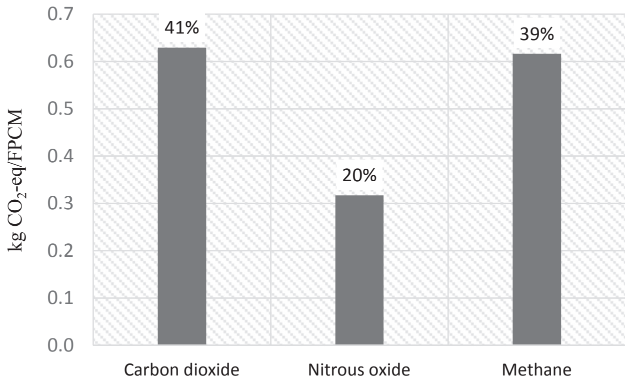

Fig. 3. Contribution of each GHG to overall CF/FPCM.

3.1. Agronomy

The average weight of feed inputs (kg dry weight) to produce one kilogram of FPCM, according to questionnaires, were corn silage 0.177 (SD 0.042), alfalfa 0.250 (SD 0.062), barley 0.222 (SD 0.047), corn grain 0.128 (SD 0.047), wheat straw 0.077 (SD 0.025), soy meal 0.067 (SD 0.017), rape meal 0.067 (SD 0.016), sugar beet pulp 0.038 (SD 0.024), sugar cane pulp 0.020 (SD 0.029), cottonseed meal 0.090 (SD 0.031) and citrus pulp 0.011 (SD 0.010). In the agronomy LC stage, the contribution percent of feed items to overall CF per FU ranged from nearly 1 to 14% depending on quantities of the ration and types of feed. Of 11 feed items, barley, corn silage, alfalfa, corn grain and wheat straw were the most highly used feed items in herd rations, and their individual share to the CF was about 0.116, 0.057, 0.230, 0.097 and 0.068 kg CO_2-eq per FU, respectively. The higher energy requirement in alfalfa production, especially use of electricity, caused this feed to contribute about 14% to the overall GHG emission. Our result showed that in the production of 1 kg of alfalfa with 85% dry weight, 0.78 kg CO_2-eq was emitted; however, a study showed that in Spain production of the same amount with 89% dry weight only emitted 0.32 kg CO_2-eq (Gallego et al., 2011). The contribution of each feed to the final CF/FU is presented in Table 1.

Table 1
Contribution of selected individual processes to overall CF.

Life cycle stage	Process	g CO_2-eq/FU	Share %
Background	Electricity mix_Iran	244	14.1
	Diesel	154	8.9
	Fertilizer-N	42	2.4
	Fertilizer-P	15	0.8
	Pesticide	4	0.2
	Transport (lorry + freighter)	149	8.6
Agronomy (as fed)	Barely	138	8
	Corn silage	57	3.3
	Alfalfa	239	13.8
	Corn grain	97	5.93
	Wheat straw	49	2.8
	Cottonseed meal	36	2.1
	Rapeseed meal	29	1.7
	Soy meal	58	3.4
Milk production	Methane-enteric	523	30.2
	Methane-manure	73	4.2
	Nitrous oxide-manure	79	4.6
Dairy processing plant	LDPE packaging film (6 g)	16	0.9
	Acid cleaner	4	0.2
	Alkaline cleaner	3.4	0.2
	Natural gas (boilers)	23	1.3
	Wastewater treatment (electricity)	80.6	4.7

3.2. Milk production

Among three LC stages, results showed that, the milk production stage had the greatest share of GHG emissions. Allocation factors between milk and beef varied from farm to farm, but the mean was 83% to milk with the standard deviation (SD) of two percentage points. Diesel and electricity inputs to animal farms per kilogram of FPCM output were 0.026 kg (SD 0.011) and 0.010 kWh (SD 0.014), respectively. Enteric methane with 0.523 kg CO2-eq per FU (30%) was the top process. In this LC stage, methane and nitrous oxide emissions from manure management also contributed to the overall impact by 4.2% and 4.6%. The average CF for 1 kg FPCM in the seven dairy farms was calculated at about 1.57 kg CO_2-eq at the farm gate; the emissions' range was between 1.15 and 2.23 kg CO_2-eq/kg FPCM. The difference in the number of milking cows on dairy farms was large (25–1206). However, no strong correlation was seen between the number of milking animals and the CF of 1 kg FPCM (correlation coefficient (r) = −0.15). The scenario analysis of the estimations showed a 10–12% variation from the average CF per kilogram of FPCM (Fig. 4).

3.3. Dairy processing

Milk processing at the dairy plant contributed about 0.163 kg CO_2-eq to the overall CF of FU. In the processing step, the major contributors were LDPE packaging film and emission caused by the wastewater treatment process with about 1 and 5% per FU, respectively. Emissions from natural gas combustion in boilers and electricity accounted for about 27% of all the GHGs emission in this LC stage. During processing of one FU, 2.8 L of wastewater with an average COD of 3200 mg/l, were also discharged into the wastewater system. The wastewater was subsequently treated mainly by the activated sludge method.

4. Discussion

Geographical and climate characteristics influence management practices in the dairy product chain. For instance, Holstein cows have adapted to the cool temperatures of northern Europe and may underperform in warm seasons in Tehran. To overcome this problem and keep profits high, air conditioning is a common process in dairy farms. Fans and water sprayers are used to cool animals' environment, which increases energy consumption and as a result GHG emissions per kilogram of FPCM. In two of the dairy farms studied, higher electricity consumption may be justified by the need to pump water from deep wells and to desalinate before use.

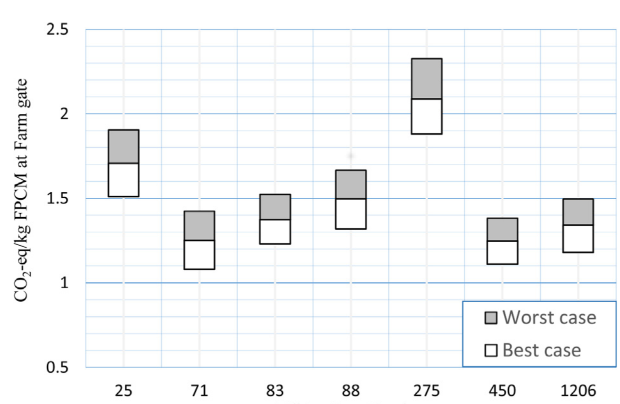

Fig. 4. Relation between the number of milking cow in the animal farms of Tehran and their CF per kilogram of FPCM. The box represents the possible highest and lowest values of estimations. The line inside the box shows the average.

The relative emissions of the three main GHGs and their share in total CO_2-eq/FPCM are presented in Fig. 3. Similar shares of CO_2 (41%) and CH_4 (39%) may be a clue to higher energy-related emissions in this study (Gerber et al., 2010; Van Kernebeek and Gerber, 2008). An LCA in Canada yielded a GHG emission of 0.92 kg of CO_2-eq/kg raw milk and the contribution of each GHG in that study was completely different from our results. In the Canadian case, methane accounted for 56% and nitrous oxide accounted for 40% of the total GHG emissions (Mc Geough et al., 2012), while for 1 kg of FPCM in our case, the values were 39% for methane, and 20% for nitrous oxide. In addition, energy-related emission on Irish dairy farms was reported to be about 5% (Casey and Holden, 2005), but our results showed that about 24% of total GHG emission was from electricity and diesel combustion.

One of the early studies of milk reported GHG emission of 1.3 kg CO_2-eq per kg milk at the farm gate in Germany (Haas et al., 2000); however, in defining the functional unit, fat or protein content was not stated clearly. When comparing various studies, attention must be paid to issues like system boundaries, allocation methods and the functional unit because they can change the results considerably. For instance, the milk product system in Iran is different from the majority of reports from the temperate regions. In those regions, because of frequent rainfalls, the cows graze in the green pasture for most of the year, and they obtain the main part of the ration directly from the land with a minimal use of the energy-intensive technologies. Moreover, in these pasture-based systems, the need for feed transportation is less. Table 2 presents some comparable studies and their allocation methods.

Our result (1.57 kg CO_2-eq/FPCM) was lower than the suggested CF of 2.4 kg CO_2-eq per kg milk at the farm gate by the FAO as the global average (Gerber et al., 2010). Still, the FAO report further emphasized 3–5 kg emissions per kg milk in western Asian countries (e.g. Iran), and it did not differentiate between traditional small-scale dairy farms and industrially managed dairy units. Therefore, we argue here that industrially managed, large-scale dairy farms may produce milk with considerably lower GHG emissions than the previously estimated carbon footprint. Nonetheless, this FAO range may be correct for the milk produced in traditional farm systems because of the lower quality of feed, inefficient dairy breeds and poor management; more studies are needed in other parts of Iran, both in traditional small-scale and industrial systems, to reasonably state a value for GHG emissions from milk production.

Our relatively higher GHG emission than that found in previous reports from developed countries might be due to higher emissions from background processes like electricity production and fuel use by machinery throughout the product chain. As a background process, electricity production comes with a so-called grid loss. Nevertheless, reducing grid loss from the estimated 15% in this study to the government's goal of 10% would only reduce CO_2-eq emissions by about 1% per FU. However, when emission of 0.91 kg CO_2-eq per kWh in Iran is compared to 0.11 kg CO_2-eq/kWh emissions from the electricity mix of Sweden (ELCD, 2008) which relies more on renewable sources like hydroelectric, then the difference can be significant.

4.1. Agronomy

The contribution of each LC stage to the overall CF/FU is presented in Fig. 2. Approximately, 43% of the overall emissions per FU come from the agronomy stage. However, this stage accounted for 47% of the emissions related to FPCM production at the farm gate, and this corresponds to 0.74 kg of CO_2-eq. The value is considerably higher than the values from temperate regions. For instance, in Belgium, feed production contributed 24% to the total emission per 1 kg of FPCM, and this corresponded to only 0.25 kg CO_2-eq (Bracquené et al., 2011). This finding, while preliminary, suggests that the agronomy stage may be the reason behind the generally higher CF from milk in this study.

There are no perennial rivers in about 70% of the country's area; hence, the agriculture sector in Iran relies on groundwater use and pumping water. As a result, the energy intensity of irrigation for growing feed is an important concern. In an Indian study, agricultural pumping contributed one-third of the overall energy (Pelletier et al., 2011). However, an Iranian investigation concluded that about 75% of total energy (both direct and indirect) for producing alfalfa was from electricity used to pump water from deep wells (Mobtaker et al., 2012). Recently, Rezae and Gholamian (2013) tested a new photovoltaic water pump system in Gorgan, Iran. They indicated that by using solar energy, 1800 L less diesel was burnt each year and the financial return was 6 years. Hence, using photovoltaic energy may be a reasonable solution to the high amounts of emissions from electricity production in Iran. It was suggested that to avert dangerous climate change, the primary need is for a radical change in energy generation technologies and energy use (McMichael et al., 2007).

4.2. Milk production

The milk production LC stage causes about 48% of the overall emissions, and it contributes 0.826 kg CO_2-eq. Enteric fermentation, the main process in the dairy farm and the product chain, produced 0.523 kg of CO_2-eq. In Ireland, the average share of enteric methane in raw milk production was 0.637 kg of CO_2-eq. However, farm systems in Ireland are usually pasture-based and enteric methane emission is expected to be higher in this type of farm system (Casey and Holden, 2005; O'Brien et al., 2012). Emissions from manure in this study were about 10% of all emissions per kilogram of FPCM at the farm gate. Therefore, emissions from enteric fermentation and manure can account for around 40% of the total raw milk's CF (1.57 kg CO_2-eq). In a methodologically comparable study in Belgium on CF of livestock products, the CF of milk was calculated from 0.9 to 1.23 kg CO_2-eq/kg FPCM at farm gate, and the most important contributions to GHG emissions were

Table 2
Comparison of some milk CF studies.

Study	Allocation method				CF (kg CO_2-eq)	
	Feed/by-products	Milk/Meat	Dairy plant	Manure (exported)	Farm-gate (FPCM)	Dairy processing (FU)
Thoma 2012 (USA)	Economic/ Physical/Mass	Bio-physical	Milk solid/ Volumetric	System separation (to crops)	1.23	0.201/kg fluid milk
Gerber/FAO, 2010 (West Asian estimate)	Economic	Protein content	Mass	As waste	3.7 (3–5)	0.25/kg FPCM
Bracquené 2011 (Belgium)	Economic	Bio-physical	Milk solid	Physical (animal 40%, crop 60%)	0.9–1.23	0.130/kg UHT milk
Present study (Tehran)	Economic	Bio-physical	Milk solid	System expansion (avoided product)	1.57	0.163/liter fluid milk

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enteric fermentation (35%), the feed production (24%) and manure (14%) (Bracquené et al., 2011).

It was shown that rations with more fibre and a lower percentage of concentrate increased methane emissions from milking cows. One study shows there are opportunities to increase feeding efficiency in the dairy farms of Tehran province by lowering the fibrous feed (e.g. straw and corn silage) and increasing the ration quality (e.g. protein concentrate) (Movafegh Ghadirli et al., 2011). Furthermore, the feed that is not converted to milk increases the environmental impact from growing feed. Nguyen et al. (2013) argued that supplementation of cattle diets with lipids rich in omega-3 fatty acids from linseed significantly decreased enteric CH_4 emissions from dairy cows also, this feeding strategy may contribute to better milk nutritional quality.

When manure is managed as a solid, it tends to decompose under more aerobic conditions, and less CH_4 is formed. According to the IPCC, the conversion rate of volatile solids in manure to methane, for the same annual average temperature (17 °C), in solid storage was 4% compared to 76% of the lagoon manure management system. Nevertheless, a higher proportion of nitrous oxide will be emitted in this aerobic condition in comparison to the more anaerobic condition of the lagoon system (IPCC, 2006). The manure management system, which overall reduced CH_4 and N_2O emissions, is favoured.

Regarding nitrogen loss from a manure management system, about a 40% and 77% N loss, are stated for solid storage and for lagoons. However, the stated coefficients of runoff/leaching may be very uncertain. The range of N loss through runoff, as suggested by the IPCC, is 3–6%. For leaching, however, the stated coefficient is less than 5% for solid storage, but a coefficient between 10 and 16% is also suggested. Because of the climate and below the world's average precipitation in this region, the selected coefficients of 3% for runoff and 4% for leaching in this study might be justifiable. It appears that solid storage is a better way of managing dairy manure in drier regions of the world like Iran, because the mainly aerobic conditions cause less methane emission, and both nitrogen runoff and leaching may be minimal. However, more research on nutrient leaching and gaseous emissions considering climate and soil properties are needed.

Many milk CF studies – mostly European – have similar GHG emissions at the farm gate, ranging from about 0.9 to 1.5 kg CO_2-eq per kg milk (Thoma et al., 2013). Similar feed items and management practices around the world for industrial production of milk from Holstein cows might be the reason behind these comparable results. Nevertheless, there are still opportunities for improvement. For instance, in a modelling study in Swiss, the authors observed that by incorporating technical means and enhancing the agronomic practices in animal farms, 20% reduction in GHG emissions was possible (Schader et al., 2013). Advances in science and dairy animal practices may further optimize milk production chain for higher profit and lower environmental impact.

4.3. Dairy processing

Of the three LC stages studied, the dairy processing had the smallest share of CF (9%). Dairy plant in the current study emits 0.163 kg CO_2-eq/FU. This value is slightly lower than the average dairy plant in the USA, where 0.201 kg CO_2-eq is emitted per kg milk. In this USA study, packaging material on average, accounted for 0.035 kg CO_2-eq per kilogram of milk (Thoma et al., 2013). In the present study, however, the LDPE pouch package was responsible for about 0.016 kg CO_2-eq per FU. Plastic pouch packaging is one of the environmentally recommended containers for packaging milk (Gerber et al., 2010). The lower weight of packaging material (6 g) per kilogram of milk and its recyclability may be the reasons for its lower contribution to the CF. Variation in GHG emissions from milk processing can be significant, and it was reported that about four times more CF was associated with small plants as compared with large plants (Milani et al., 2011).

In Europe, estimates show that 1.2% of the milk solid become waste during processing (Flysjö, 2012). However, our preliminary studies found 3.5–5% milk solid loss and about 5 m^3 water use per 1000 kg of the processed milk for the whole plant. Higher organic and hydraulic loads in addition to inefficient treatment processes may be the reasons for high electricity use or GHG emissions from wastewater treatment processes. Milk losses usually result in three negative effects: first, the futile environmental burdens from the production of this lost milk; second, a high organic load in the generated wastewater that needs further electricity for treatment; and third, a negative economic impact.

In warmer regions with a higher organic load of wastewater, the up-flow anaerobic sludge blanket (UASB) method could be a promising substitute for the energy-intensive activated sludge method. Biogas production and lower cost of sludge disposal are among some of the advantages of the UASB method. In a brewery industry case, wastewater treatment using the UASB method reduced energy expenditure by 60% (Cakir and Stenstrom, 2005; Scampini, 2010).

Some researchers consider milk to not be an environmentally benign product because of its high environmental impacts. Among the suggestions to lower the CF of human food production and consumption are proposals to alter food consumption patterns by replacing animal foods with more plant-based foods. However, in Iran, consumption of milk is lower than the global average of about 100 kg milk/year per capita (OECD-FAO, 2011), and the normalization step shows that GHG emissions from pasteurized fluid milk production contribute by 0.62% to the total per capita GHG emissions in Iran. Moreover, a study that compared the CF of different beverages shows that milk has a relatively low CF when the nutritional value is taken into account (Smedman et al., 2010). Researchers suggest the possibility of adopting a functional unit such as a nutritional value expressed as calorific value or protein content (Więk and Tkacz, 2013). After all, attention must be paid to never using CF as a proxy for all the types of environmental impact that may occur during production of a product. For a more holistic view, a complete LCA may be advisable.

5. Conclusion

Few studies have been done on CF of dairy products in developing countries; however, the share of dairy products in the developing nations' diet will continue increasing (Gerosa and Skoet, 2013). Our results showed that production of one litre of packaged milk emitted 1.73 kg CO_2-eq from cradle to gate, and about 90% of the total emissions were from milk production at the farm gate. Moreover, the findings showed that emissions from electricity production had a considerable impact on the overall result by about 14%. Our results suggest that the CF value is considerably lower than what has been estimated by international organizations like the FAO. Still, the CF result was higher than values reported in previous studies from developed temperate countries.

In fact, considering the level of industrialization and geographical circumstances, the CF of packaged milk is rather tolerable, when compared to findings in studies in developed countries. The lower emission coefficient of the manure management system in this region and complete use of manure as a fertilizer may have partly offset the higher energy-related emissions in the product chain. One promising strategy for reducing energy-related emissions is the use of photovoltaic energy in dairy farm and agronomy stages, for instance, to pump water.

The results of this study may serve as a benchmark for future studies of the dairy sector in Iran. The Iranian dairy industry needs more research on its environmental aspects in different regions and other milk production systems, for example, traditional systems.

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