ISSN 0101-2061 (Print)
ISSN 1678-457X (Online)
Food Science and Technology

DOI: http://dx.doi.org/10.1590/1678-457X.02717

Carbon footprint assessment for a local branded pure milk product: a lifecycle based approach

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Abstract

This paper provides a simplified life cycle based assessment for a local branded pure milk product, to measure its related carbon footprint, including production of raw milk, dairy processing, transportation of milk product and disposal of packaging waste. The results show that the total carbon footprint of the pure milk is 1120g CO_2/L. The production of raw milk is identified as the major contributor to the carbon footprint. This contribution has amounted to 843 g of CO_2 per liter of pure milk, accounted for 75.27% of the total carbon footprint. The carbon footprint of product transportation is 38 g of CO_2 per liter, which accounts for 3.39% of the total. The carbon footprint related to the dairy processing and disposal of waste packaging is 173 g of CO_2 per liter and 66 g of CO_2 per liter, accounting for 15.45% and 5.89% of the total, respectively. The carbon footprint assessment intends to help dairy enterprises identify the intensive sectors of carbon emissions, and provides insight into improvement of product environmental performances.

Keywords: pure milk; carbon footprint; life cycle; life cycle based assessment.

Practical Application: This study identifies the most carbon-intensive sector in the life cycle of a pure milk product in China.

1 Introduction

Global climate change has become a worldwide challenge, sourced by Greenhouse gas (GHG) emissions which poses risk to the living environment, health, and safety of human beings (Mantyka-Pringle et al., 2015). Agricultural production is an important source of GHG emissions, accounting for 15 to 25% of the total anthropogenic GHG emissions, of which dairy products constitute approximately 5% (Laratte et al., 2014; Hawkins et al., 2015). China is the third world largest consumer of dairy products (Hagemann et al., 2012; Huang et al., 2014). The GHG emissions associated with dairy products are increasing annually, due to a continuous rise in consumer demand (Baek et al., 2014; Adler et al., 2015). With "green consumerism" gaining increasing influence on the market, development of low-carbon food is a practical need for the food industries to reduce their GHG emissions, as well as to pursue long-term commercial success (Beske et al., 2014; Biggs et al., 2015). Carbon footprint, is an effective indicator to embody the low-carbon concept, regarded as the total carbon emission of a certain product or service during its entire life cycle (Vergé et al., 2013; Dong et al., 2014).

A number of studies have conducted measuring the carbon footprint of dairy products, by using the life cycle assessment (LCA). For example, Cederberg & Mattsson (2000) compared conventional production with organic production in terms of material, energy input, and environmental output, which showed that the organic milk had a smaller carbon footprint. The similar result was identified by Thomassen et al. (2008) and Flysjö et al. (2012), who identified that the organic milk production generated less GHG than the conventional production. Eide (2002) measured carbon emissions during entire life cycle of milk, including agricultural product input, milk production, transportation, and waste disposal. The results indicated that the agricultural product input was the largest contributor to the carbon footprint. Specifically, Hospido et al. (2003) found that the carbon footprint produced by feeding of dairy cows was the largest. On this basis, Rotz et al. (2010) employed LCA to identify that the feed level may have a significant impact on the milk carbon footprint. By using LCA to calculate the carbon footprints of 11 dairy products, Vergé et al. (2013) further pointed out varying climate and dairy herd management could also have an impact. González-García et al. (2013) used LCA to measure the carbon footprint of yogurt, and found that carbon footprints in raw milk production and processing were the largest. O'Brien et al. (2014) employed LCA to compare carbon footprint of dairy products from high-performing confinement and grass-based dairy farms in the United States and the United Kingdom. They further incorporated the economic performances of dairy farms into the calculation of the carbon footprint, in order to achieve an outcome that was mutually beneficial for the economy and the environment (O'Brien et al., 2015).

The previous studies are useful in informing our approach. However, the conventional LCA, due to its complexities in required data acquistion, system boundary division etc., is difficult for engineers to implement in real applications (Chen & Corson, 2014). This study is expected to provide a simplified assessment

Received 19 Jan., 2017
Accepted 01 Apr., 2017
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approach based upon a LCA framework of milk, mainly focuses on presenting its carbon emissions information to consumers, to help local dairy enterprises identify the most carbon-intensive sector of the whole life cycle, especially encourage the dairy enterprises with a higher environmental morality to have a product carbon labelling attempt, thus to provide effective measures for emissions reduction in dairy supply chain.

2 Material and methods

LCA is to assess possible environmental impact based upon the quantitative survey of a product during its whole life cycle, by identifying environmental emissions of all materials and energy, to seek opportunities on improvement of product environmental performances (Huysveld et al., 2015). As defined by International Organization for Standardization (ISO), a precise LCA generally follows by four phases: Goal and scope definition, Life cycle inventory analysis (LCI), Life cycle impact assessment (LCIA), and Interpretation (AzariJafari et al., 2016). Compared with the conventional LCA, the process of life cycle impact assessment is simplified in this study, as it mainly uses different categories of indicators to elaborate results of life cycle inventory (Nigri et al., 2014). However, only the product carbon footprint is considered in the impact category as the global warming potential, represented by kg CO2e per kg emission. Other impacts, such as eutrophication, acid rain potential, toxicity etc., have been omitted in this study. As a lifecycle study may not always need to use impact assessment, the results of the LCI provide information of a product system, including all inputs and outputs in the form of elementary flows (Seppälä, 2003), which is used to quantify the impact of carbon emissions in this study.

The Tetra Pak 1litre pure liquid milk is selected to assess its lifecycle based carbon footprint. System boundary is a key component of LCA, which directly affects the assessment precision (Park et al., 2016). This study only focused on processes that directly contributed to pure milk production, that is, only the effects of energy and material input and carbon emissions, as shown in Figure 1. The system boundary of milk life cycle is thus simplified and divided into four stages, namely, raw milk production, dairy product processing, product transportation and packaging waste disposal.

The carbon footprint is comprised of two parts, namely, direct GHG emissions and indirect GHG emissions, as shown in Equation 1 (IPCC, 2006):

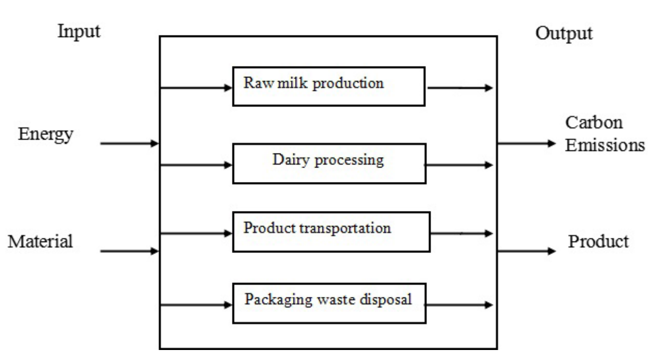

Figure 1. System boundary of a pure milk product.

$$GHG_{total} = GHG_{direct} + GHG_{indirect} \quad (1)$$

The direct emissions could be obtained by monitoring chemometrics, mass balance, or similar methods, and are calculated by using the following Equation 2 (IPCC, 2006):

$$GHG_{direct} = \sum_{i=1}^{n} D_i \times GWP_i \quad (2)$$

where i refers to the ith emissions source of milk life cycle, D the activity level, GWP the global warming potential.

The indirect emissions are calculated by using the following Equation 3 (IPCC, 2006):

$$GHG_{indirect} = \sum_{i=1}^{n} A_i \times E_i \quad (3)$$

where i refers to the ith emissions source of milk life cycle, A the activity level, which involves the amount of all resource and energy during the product life cycle (material input and output, energy use, transportation distance, etc.) E is the GHG emission factor, which refers to the GHG produced per unit activity level, derived from life cycle databases and industrial reports.

2.1 Case background

The milk source base is located at Hongya Country, Southwestern Sichuan Province, China, about 147 kilometres far from Chengdu City, the provincial capital. The diary processing plant is located at Pixian, suburb of Chengdu City, which is about 175 kilometres far from the milk source base. The branded milk is mainly distributed to the central Chengdu City, about 40 kilometres distances from the diary processing plant. The milk packaging waste is transported to the municipal landfill for final disposal, about 30 kilometres away from the central city. The detailed geographic distribution of the milk supply chain network is shown in Figure 2.

2.2 Source of inventory data

Table 1 shows the inventory data during the raw milk production stage, which are obtained by analogy to Hospido et al. (2003) on milk LCA. The location of the raw milk production is dairy farms, where the main consumptions are fodder, electricity, and diesel. From a conversion of the results obtained by Hospido et al. (2003) on GHG emissions factors from farm fodder and equipment disinfectant, a corresponding CO_2 emission coefficient is obtained for the calculation. The electricity emission factor is based on the 2014 Baseline Emission Factors for Regional Power Grids in China, released by National Development and Reform Commission, of which the Central China power-grid emission factor is used in this study. The operating margin emissions factor is 0.972 t CO_2/MWh, and the build margin emissions factor is 0.47 t CO_2/MWh (NDRC, 2014). Through the conversion, the power grid emission factor is 0.723 kg/kW·h.

Table 2 shows the inventory data of the dairy processing stage. Specifically, a large amount of water is needed during the cooling and pre-heating of raw milk, as well as the pre-heating

Figure 2. The geographic distribution of the local branded milk supply chain.

and sterilization of the liquid milk. Electricity is mainly used for operating the equipment, and fuels are used to generate the steam required for the pre-heating and heating of the sterilizer (Riera et al., 2013). Cardboard paper is used to produce the outer packaging for the milk.

The carbon footprint of product transportation is calculated by transportation loads (tonne·km) multiplying the carbon emissions factor (Cai et al., 2012). According to the field investigation, light-weight gasoline truck in 2 tonnes of loading capacity is employed to transport the raw milk from the pasture to the processing plant, then to the distribution centre, and their distances are 175 kilometres and 40 kilometres, respectively. Heavy-weight disel truck in 10 tonnes of loading capacity is employed to transport the packaging waste to the municipal landfill, with a distance of 30 kilometres. The carbon emissions factors of gasoline and diesel are measured by IPCC (2006), as 164 g per tonne kilometer for 2 tonnes light-weight gasoline truck, 84.8 g per tonne kilometer for 10 tonnes Heavy-weight disel truck, respectively, as shown in Table 3.

Recycling is selected for the packaging waste pre-treatment. Because of the separation technique for aluminum-plastic

Table 1. Inventory data of the raw milk production.

Emissions type	Emissions source	Activity level	CO_2 emissions factor	Source of emissions factor	Carbon footprint (g)
Energy	Electricity	0.047kW·h	0.723 kg/kW·h	NDRC (2014)	34
	Diesel	3.68 ml	2.73 g/ml	IPCC (2006)	10
Material	Fodder	1290 g	0.403 g/g	Hospido et al. (2003)	522
	Disinfectant	1.59 ml	1.79 g/ml	Hospido et al. (2003)	2.85
	Water	2.66 L	0.009 g/L	Field investigation	0.25

Table 2. Inventory data of the dairy processing.

Emissions type	Emissions sources	Activity level	CO_2 emissions factor	Source of emissions factor	Carbon footprint (g)
Energy	Diesel	7.07 g	2.73 g/ml	IPCC (2006)	22.8
	Electricity	0.047 kW·h	0.723 kg/kW·h	NDRC (2014)	33.5
Material	Cardboard paper	16.8 g	1.04 g/g	DEFRA (2012)	17.4
	Membrane	0.183 g	2.85 g/g	WRI (2004)	0.522
	Equipment cleaning	2.91 g	0.649 g/g	Field investigation	1.89
	Tetra Pak	1.01 U	0.952 g/U	Field investigation	96.1
	Water	4.41 L	0.094 g/L	Field investigation	0.415

Table 3. Inventory data of the product transportation.

Transportation sub-stages	Activity level (t·km)	CO_2 emissions factor (g/t·km)	Source of emissions factor	Carbon footprint (g)
Raw milk transportation	0.175	164	IPCC (2006) Cai et al. (2012)	28.7
Milk distribution	0.04	164	IPCC (2006) Cai et al. (2012)	6.55
Packaging waste Transportation	0.03	84.8	IPCC (2006) Cai et al. (2012)	2.54

composites usually with a lower heating value, these containers are not suitable for incineration (Xie et al., 2011). Therefore, landfill disposal is the ultimate choice (Meneses et al., 2012). Data on the carbon emissions during the landfill stage are by analogy to Cherubini's inventory of sanitary landfill disposal (Cherubini et al., 2009), shown in Table 4.

3 Results and discussion

The carbon footprints related to the four stages are listed in Table 5. The results show that for a typical 1L Tetra Pak of pure milk, the carbon footprint for its whole life cycle is 1120g, of which 843g is generated during the raw milk production, accounting for 75.27% of the total carbon footprint. The second stage is that of dairy processing, for which the carbon footprint is 173g, accounting for 15.45%. The third stage of product transportation contributes 38g of the carbon footprint, accounting for 3.39%. The carbon footprint in the stage of packaging waste disposal is 66g, accounting for 5.89%.

3.1 Carbon footprint of the raw milk production

The carbon footprint of the raw milk production is 843g, which is identified as the major source of the carbon footprint in the milk lifecycle. Specifically, farm fodder, such as corn and silage are the largest contributors (522g), accounting for 46.61% of the total carbon footprint. The methane emissions of dairy cows are the second highest, with a carbon footprint of 273g, accounting for 24.38% of the total carbon footprint, as shown in Figure 3. This may be attributable to the ruminant digestive system of dairy cows, thus may give rise to a large amount of methane (Wang et al., 2016).

3.2 Carbon footprint of the dairy processing

In the dairy processing stage, the carbon footprint is 173g, accounting for 15.45% of the total. Figure 4 shows that the major emissions source is the Tetra Pak production, which has a carbon footprint of 96g, accounting for 8.58% of the total. Electricity and diesel energy consumption contribute 34g and 23g of carbon footprint, respectively, which account for 2.99% and 2.04% of the total. The carbon footprint of cardboard production is 18g, accounting for 1.56% of the total. The carbon footprint contributions of water and membranes are relatively low (both <0.1%).

3.3 Carbon footprint of the product transportation

The product transportation is consisted by three sub-stages, as raw milk transportation, milk distribution and packaging waste transportation. Raw milk transportation has a carbon footprint of 29 g, accounting for 75.91% of the carbon footprint at this stage. Milk distribution and transportation of packaging disposal contribute 7g and 3g of carbon footprint respectively, which account for 17.35% and 6.74% of the carbon footprint at this stage, as shown in Figure 5.

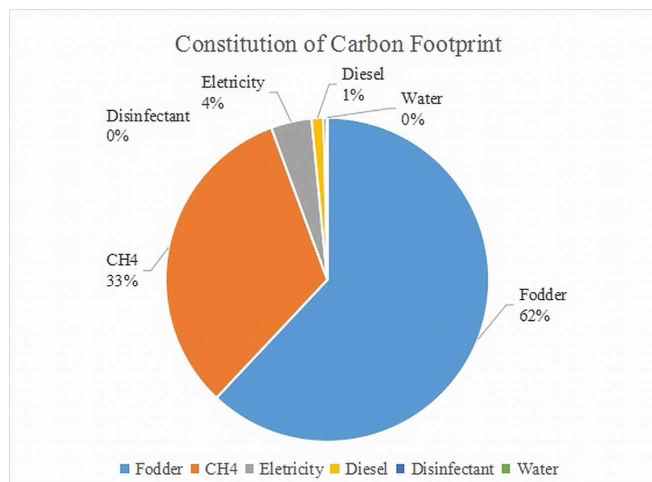

Figure 3. Carbon footprint of the raw milk production.

Table 4. Inventory data of the packaging waste disposal.

Emissions type		Emissions source	Activity level	CO_2 emissions factor	Source of emissions factor	Carbon footprint (g)
Recycling	Energy	Raw coal	9.03 g	2.69 g/g	IPCC (2006)	24.3
		Natural gas	4.63×10^{-10} m^3	2.09 kg/m^3	IPCC (2006)	9.68×10^{-10}
		Crude oil	0.00776 g	3.07 g/g	IPCC (2006)	0.0238
		Electricity	0.0114 kW·h	723 g/kW·h	NDRC (2014)	8.24
		CO_2	15.5 g	1.00 g/g	DEFRA (2012)	15.5
		CH_4	0.0843 g	25 g/g	DEFRA (2012)	2.11
Landfill disposal			12 g	1.31 g/g	Cherubini et al. (2009)	15.7

Table 5. Carbon footprint of different lifecycle stages.

Emission types	Carbon footprint (g CO_2 per litre)	Percentage (%)
Raw milk production	843	75.27
Dairy processing	173	15.45
Product transportation	38	3.39
Packaging disposal	66	5.89
Total	1120	100

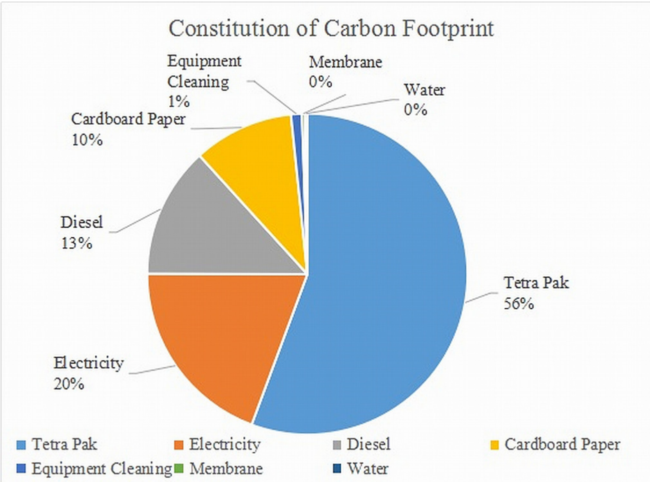

Figure 4. Carbon footprint of the dairy processing.

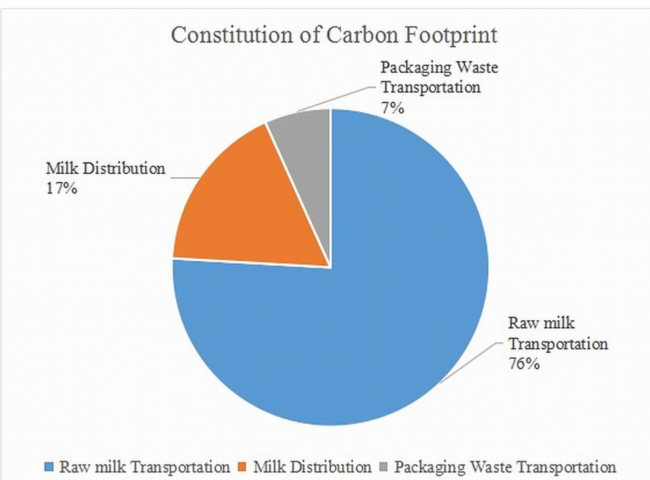

Figure 5. Carbon footprint of the product transportation.

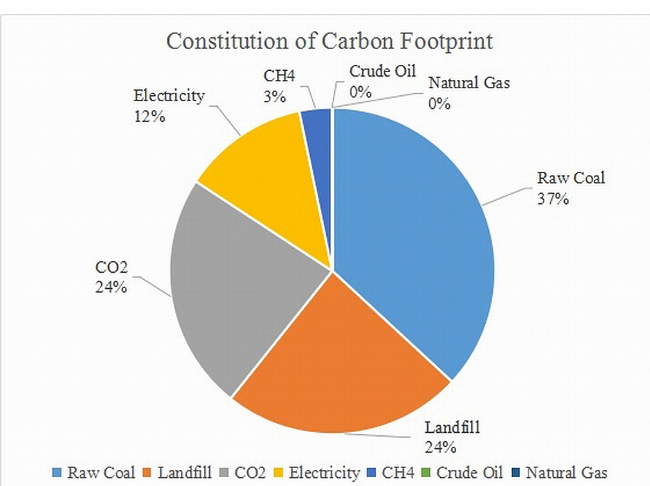

Figure 6. Carbon footprint of the packaging waste disposal.

3.4 Carbon footprint of the packaging waste disposal

At the packaging waste disposal stage, the carbon footprint is 66g, accounting for 5.89% of the total. Figure 6 indicates that the major emissions source is raw coal consumption, which has a carbon footprint of 24g, accounting for 36.87% of the carbon footprint at this stage. Landfill disposal is the second highest, which has a carbon footprint of 16g, accounting for 23.82% of carbon emission at this stage. The carbon footprint associated with direct CO_2 and CH_4 emissions are 15g and 2g, which account for 23.52% and 3.2% of carbon emissions at this stage, respectively. Electricity consumption contributes 8.24g of carbon footprint, which is 12.50% of the carbon footprint at this stage. As the consumption of crude oil and natural gases is relatively low, the contributions to the carbon footprint account for less than 0.05%.

3.5 Discussion

The carbon footprint refers to the total carbon emissions of a certain product or service during its entire life cycle, directly or indirectly emitted by agents (individuals, organizations, or departments) during a certain activity (Zhao et al., 2012). LCA aims to help enterprises and organizations in assessment of environmental impact of whole supply chain of a product, identify most intensive emissions sector, thus to propose effective measures for emissions reduction, and optimize resource distribution and utilization (Kulak et al., 2016). However, many uncertainties still remain in product carbon footprint assessment, e.g., various assessment standards may give rise to different results (Liu et al., 2016). For the simplified approach, the specific uncertainties regarding to the assessment results are: ① different division of system boundaries may lead to deviation in carbon footprint assessment. The system boundary of the study has been strictly defined, which only contains four procedures related to the pure milk product, i.e., raw milk production, dairy processing, product transportation and packaging waste disposal. However, the upper stream of the raw milk production, e.g., the raw milk source, as well as the downstream of product transportation, e.g., the product use, has been deliberately omitted from the system boundary. ② the simplified approach mainly focuses on the inventory analysis for the impact assessment, which is quantified by the activity level multiplying the emissions factor. With regard to the activity level, it is closely related to the data acquaintance. However, there may be difficulties in obtaining the required data, thus limits the precision of calculated values. Emissions factor is another critical input for the impact assessment. Although some of the emissions factors have been measured by the field investigation, a number of factors, such as energy sources (electricity, diesels), fodder, disinfectant etc., are derived from the similar studies. Thus, there may be biases in the assessment results.

The results indicate that the largest contributor to the carbon footprint occurred at the acquisition stage of the raw milk, which accounts for 93.90% of the total carbon footprint. The results are consistent with those of the study by González-García et al. (2013), which has indicated that raw milk production generated the highest carbon footprint (80 to 90%) in the yogurt life cycle. Raw milk is considered taking from conventional dairy farming in the study, through which the carbon footprint at this stage accounts for 75.27% of the total. In the study by Hospido et al. (2003), the carbon footprint of the subsystem related to breeding during the farming stage accounts for 80.32% of the total carbon footprint, which is similar to the results of our study. Fodder has an impact on the GHG emissions related to dairy cows, and especially the ratio of the ingredients in the mixed animal fodder has a significant influence (Castanheira et al., 2010). Based upon our field investigation, dairy cows are fed large amounts of coarse fodder due to its low cost. However, digesting this type of fodder may increase CH_4 emissions (Muñoz et al., 2015; Hatew et al., 2016). Adjustment of the ratio of corn and coarse fodder in the animal feed may contribute to limiting the amounts of GHG being emitted (Van-Middelaar et al., 2013). In addition, Excessive nitrogen fertilizer has been applied in the agricultural sector of China for a long time (Ha et al., 2015). The fertilizer in the soil would release N_2O by denitrification and in this way increase GHG emissions (Rowlings et al., 2013). Thus, to create an effective balance between nutritional value and environmental impact is significant to be considered in fodder ingredients (Dutreuil et al., 2014).

The packaging-waste disposal contributes 5.89% to the total carbon footprint. In China, landfilling is mostly used to dispose of paper-aluminum-plastic composite packaging. However, it may cause the generation of harmful non-degradable substances (Woon & Lo, 2013).To increase the recycling ratio may significantly mitigate the adverse environmental impact of the packaging waste disposal, in which development of aluminum-plastic separation technology is effective.

Currently, the implementation of carbon footprinting is voluntary for enterprises, who may consider assuming additional social responsibilities to improve the 'green performance' of their products (Noronha et al., 2013). However, additional cost for such a holistic carbon footprint assessment may give rise to uncertainty regarding commercial success (Zhao et al., 2013). For this reason, government should assume a leading role on the path to sustainability, e.g., motivates green innovation among enterprises through well designed policy instruments, to help enterprises achieve a 'win-win' performance between the environment and the economy (Zhao et al., 2016). Governmental policy instruments can be divided into the incentive and punitive mechanism, in which the former contains subsidy, tax preference, price regulation etc. to decrease financial risk in green transition, whilst the latter mainly focuses on compulsive measure, i.e., economic sanction, to drive product innovation (Zhao et al., 2017). In addition, the external force from consumers is also a decisive factor to drive the enterprises to have the carbon footprinting attempt. With consumers' environmental awareness being gradually increased, their purchasing intention and willingness to pay may be influenced by a product carbon label, i.e., a tag summary to present the information of carbon footprint throughout a product lifecycle (Zhao et al., 2012; Aung & Chang, 2014). For instance, recent investigation shows that 50% of consumers in UK have chosen at least one carbon-labeled item while shopping in Tesco (Zhao et al., 2012). This would provide such business opportunities for enterprises to benefit from the sale of carbon labelled products, thus to cover the additional cost of carbon footprint assessment.

4 Conclusions

A simplified life cycle based assessment is employed to calculate the carbon footprint of a pure milk product, which is based upon the inventory analysis. The result indicates that the carbon footprint mainly relates to the production of raw milk at the farm, contributing 75.27% to the emissions, whereas dairy processing, product transportation and disposing of the packaging waste contribute 15.45%, 3.39% and 5.89%, respectively. As regards the raw milk production, carbon footprint may be reduced by adjusting the proportions of the animal fodder, thereby contributing to a reduction of the total carbon footprint. It is expected that this study may give insight to provide a transparent carbon emissions information to consumers, to encourage the dairy enterprises to implement emissions reduction related activities, thus to promote a low-carbon dairy industry. Further studies will focus on the improvement of the assessment, including the quality of data sources, sensitivity analysis etc., in order to measure the carbon footprint of milk products more precisely.

Acknowledgements

This study is sponsored by National Natural Science Foundation of China (No. 41301639; No. 41571520), Sichuan Provincial Key Technology Support (No. 2014GZ0168), and The Fundamental Research Funds for the Central Universities (No. A0920502051619).

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