Water availability footprint of dairy production in Northeast China

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ABSTRACT

As China's dairy consumption is growing, both the domestic milk production and the importation of dairy products are increasing to meet demand. Life cycle assessment (LCA) has recently been applied to assess the water availability footprint for dairy production systems in the major production region of Heilongjiang (Huang et al. 2014). Comparisons were also made with milk produced in the US (California) and New Zealand. The water footprint of milk (cradle to farm gate) produced in Heilongjiang was around 11 L H_2Oe (H_2O-equivalents) kg^{-1} fat-protein-corrected milk (FPCM). This compared to 461 and 0.01 L H_2Oe kg^{-1} FPCM for milk in California and New Zealand respectively. These results suggest that large-scale milk production systems in north-east China, with little dependence on irrigation, have only a modest impact on freshwater availability. Further expansion of the Chinese dairy industry should avoid farming systems with high consumptive water requirements in water-stressed regions.

Keywords: dairy farming, agri-food sector, life cycle assessment, water footprint, sustainable water use

1. Introduction

The environmental burdens of livestock production are a major concern (Herrero and Thornton 2013), especially impacts related to greenhouse gas emissions, land and water use (IDF 2010; Mekonnen and Hoekstra 2012; Stehfest et al. 2013). As livestock production in developing countries is expected to increase, these problems are likely to become even more pressing. China is the world's most populous country and with rapid economic growth diets have shifted toward more calories from animal fats and proteins. From 1990 to 2009, China's dairy consumption increased from 6 to 30 kg per capita per annum (FAO 2012). In response to the growing demand, domestic milk output has increased as well as net imports of dairy products. The expanding Chinese dairy industry has been examined from a range of environmental perspectives (Liu et al. 2004; Sun et al. 2010; Wang et al. 2010). This paper, based on a recent article (Huang et al. 2014), specifically addresses concerns related to water depletion, which is a prominent environmental concern in much of northern China.

According to previous studies using the virtual water approach, which only reports the volumes of water used in production, the increase of livestock production was reckoned as the main driver of China's water scarcity (Liu et al. 2008; Liu and Savenije 2008). However, this argument is built on the general situation that animal products have higher virtual water than crop products (e.g. 1,644 m^3 ton^{-1} of cereals; 15,415 m^3 ton^{-1} of beef) (WFN, 2012). Such volumetric water footprints, which give no consideration to the environmental relevance of water being used, have been described as potentially confusing and misleading (Ridoutt et al. 2009; Zonderland-Thomassen and Ledgard 2012), often giving the largest values to rain-fed agricultural production systems which are actually not associated with any water withdrawal. Environmental relevance should be taken into consideration if the water footprint indicator is to inform wise decision making and policy development (Pfister et al. 2011; Ridoutt and Huang 2012), and this is the direction a new international standard for water footprint is taking (ISO 14046). Several LCA-based water footprinting methods which enable accounting and impact assessment of water use are now available (e.g. Bayart et al. 2010; Mila i Canals et al. 2009; Pfister et al. 2009; Ridoutt and Pfister 2010). Compared to volumetric-oriented indicators such as virtual water, impact-oriented indicators are recommended as being more revealing for decision making (Berger and Finkbeiner 2013; Ridoutt and Pfister 2010; Zonderland-Thomassen and Ledgard 2012).

However, to our knowledge, the application of LCA-based water footprinting to Chinese dairy production is scanty. We conducted a detailed inventory of life cycle water consumption of dairy production in Northeast China (Huang et al. 2014). The water footprints of milk of Chinese origin were subsequently compared with milk produced in countries which are significant in their exports of dairy products to China. Our main purpose was to offer strategic insights to the Chinese food industry about ways to improve the sustainability of products

Jing Huang and Ling Du contributed equally to this study.

containing dairy ingredients from a consumptive water use perspective. The wider dissemination of results is also intended to increase understanding of sustainable water use in relation to China's expanding dairy industry.

2. Methods

2.1. System description

The growth of China's milk output over the past decades has mainly resulted from the expansion of the national dairy herd (0.64 million head in 1980 to 14.2 million head in 2010, DAC 2011) and a shift in production patterns from household to large-scale dairy farms. Milk production mainly occurs in northern China, which in 2010 had more than 80% of the national herd (NBSC 2011). This study concerns the large-scale milk production systems in the north-eastern province of Heilongjiang which is the second largest in terms of milk output. In this region, dairy cows are predominantly raised in mixed farming systems where crop products such as maize, wheat bran and soybean meal are used as feed for the cows. The annual rainfall ranges between 400 and 600 mm, and is concentrated during spring and autumn. Supplementary irrigation is necessary for maize, wheat and soybean. Forage crops such as silage maize and grass are generally rain-fed.

2.2. Life cycle inventory

An LCA based-water footprinting method was used to assess consumptive water use in the production of raw milk (Ridoutt and Pfister 2010). This study only took into account the way the production system limits the availability of freshwater for the environment and for other human uses. As such, only the consumptive water use from surface and groundwater (so-called blue water) was considered. The consumption of soil moisture derived from natural rainfall (so-called green water) was included to estimate the blue water consumption. However, green water will be disregarded in the impact assessment phase (section 2.3) because green water does not generally contribute to regional freshwater scarcity in water bodies (Mila i Canals et al. 2009; Ridoutt and Pfister 2010).

The dairy farming subsystem was modeled using first-hand survey data collected from four large-scale dairy farms and covered the 2011 financial year (Table 1). Capital goods used in production (e.g. machinery and buildings) and dairy farm services (e.g. veterinary and business services) were not included in the assessment as these items are difficult to ascertain and are of minor environmental relevance in most open farming systems (Ridoutt et al. 2012). Maize, maize silage and hay were either grown on-farm or purchased from local crop farmers. Soybean meal and wheat bran were purchased from local oil extraction and grain milling industries which were processing local crop products. In this region, on-farm water use was from groundwater. Effluents such as urine and dung were regularly collected and stored in ponds for 30 to 180 days then returned to local croplands for feed production. Further information regarding the irrigation and other farm inputs used to produce purchased feed crops were collected from local farms and by consultation with local experts (Table 2).

Water consumption associated with the production of farm inputs (fuels, fertilizers, etc) was determined using the Chinese Life Cycle Database (CLCD; www.itke.com.cn). Water consumption was expressed relative to the amount of fat and protein corrected milk (FPCM, 4.0 % fat and 3.3 % protein, FAO 2010). For the allocation of water consumption from processes with multiple co-products, there are several available methods such as the biophysical, economic and protein-based allocation methods (Gerber et al. 2010; Guinée et al. 2004; Thoma et al. 2013). This study applied both the biophysical and economic approaches, enabling the results to be compared with other studies applying these same methods. Application of the biophysical approach followed Thoma et al. (2013). The incoming feed energy was estimated from the surveyed quantity of beef and milk produced and the known nutritional characteristics of the specific feeds consumed by the animals (Gao 2009). The ratio of the feed energy deposited as milk to the total feed energy deposited as milk and beef was then used to define the allocation ratio. The economic approach to allocation used average prices over the last five years.

2.3. Impact assessment

Impact assessment was used to assess the environmental relevance of consumptive water flows in relation to freshwater scarcity. Local characterization factors for freshwater consumption were taken from the Water Stress

Index (WSI) of Pfister et al. (2009). The WSI of the study region was 0.125 and the national average WSI for China (0.478) was used in relation to farm and industrial inputs where the location of production was uncertain. As for the water footprint, each instance of consumptive water use was multiplied by the relevant WSI and then summed across the product life cycle. To enable comparisons between products produced in different regions, the water footprint was then normalized by dividing by the global average WSI (0.602; Pfister et al. 2009) and expressed in the units H_2O equivalents (H_2Oe).

Table 1. Characteristics of the dairy farming subsystems in Heilongjiang, China.

Variable [a]	**Value**
Livestock	
Average number of heifers <2 yr old, head	90
Average number of milkers, head	110
Average number of dry cows, head	30
Average number of bulls, head [b]	0
Average number of mortality and replacement, head	15
Annual milk production, t $farm^{-1}$	693
Fat content, %	3.5
Protein content, %	3.0
Feed	
Maize, t $farm^{-1}$	439
Maize silage, t $farm^{-1}$	1128
Soybean meal, t $farm^{-1}$	165
Wheat bran, t $farm^{-1}$	97
Hay, t $farm^{-1}$	222
Other Farm inputs	
Drinking water use, t $farm^{-1}$	7300
Dairy shed water use, t $farm^{-1}$	1460
Electricity, kwh $farm^{-1}$	2000
Coal, t $farm^{-1}$	20
Diesel, t $farm^{-1}$	4

[a] All figures are presented on a yearly basis, yr^{-1}.
[b] Artificial insemination

Table 2. Characteristics of the crop farming subsystems in Heilongjiang, China.

	Maize (grain)	**Maize (silage)**	**Wheat**	**Soybean**	**Hay**
Irrigation, m^3 ha^{-1}	266	0	1260	115	0
Diesel, kg ha^{-1}	23	0	22	21	0
Pesticide, kg ha^{-1}	1.9	2.4	1.3	2.8	0
Fertilizer, kg ha^{-1}					
N	160	200	240	45	60
P_2O_5	50	90	130	80	19
K_2O	45	45	53	45	50
Yield, kg ha^{-1}	9500	85000	3350	1850	2000

2.4. Sensitivity analysis

LCA studies are frequently influenced by uncertainties arising from different factors (Bjorklund 2002). Following ISO 14044 (2006), this study applied sensitivity analysis to the allocation rules and data uncertainty, using the data collected from high and low input farms identified from the four that were surveyed.

2.5. Comparison of milk produced in other countries

The water footprint of milk produced in Heilongjiang was compared with production in the US (California) and New Zealand as imports of dairy ingredients from these regions are important to the Chinese food industry. Lacking detailed information on dairy farms in these two regions, related data for raw milk at farm gate were collected from literature and adjusted to the FPCM functional unit where necessary (Asselin 2012, USDA 2007, Zonderland-Thomassen and Ledgard 2012).

3. Results

3.1. Water consumption of milk produced in Heilongjiang and sensitivity analysis

For large-scale dairy production systems in Northeast China, the allocation of resource use to milk was 92.3% using a biophysical allocation method and slightly higher at 95.2% using an economic allocation method. Consumptive water use also varied between farms, such that the water use allocated to the production of 1 kg fat-protein-corrected milk (at farm gate) varied from 65.4 to 75.3 L (biophysical allocation method) and from 67.3 to 77.7 L (economic allocation method) (Table 3). The average blue water consumption across the four surveyed dairy farms in Heilongjiang was 69.0 L kg^{-1} FPCM (biophysical allocation), with 83% occurring in the production of feed (Table 4). The sensitivity analysis indicated that the variations between high and low input farms were more important than choice of allocation method. That said, the uncertainty associated with data was not regarded as significant in terms of influencing the comparative ranking of water footprint results for milk originating from Heilongjiang, NZ and California (Section 3.2 following).

Table 3. Water consumption of milk produced in Heilongjiang and sensitivity check on allocation rule.

Water consumption per unit milk	High input farm	Low input farm	Difference
Biophysical allocation method, L kg^{-1} FPCM	75.3	65.4	9.9
Economic allocation method, L kg^{-1} FPCM	77.7	67.3	10.4
Deviation, L kg^{-1} FPCM	2.4	1.9	0.5
Deviation, %	3.2	2.9	5.1

Table 4. Water consumption of milk produced in Heilongjiang and sensitivity check on data uncertainty.

Water consumption per unit milk [a]	Feed production	Dairy farm operation	Total
Average value, L kg^{-1} FPCM	57.3	11.7	69.0
High input farm, L kg^{-1} FPCM	62.8	12.5	75.3
Deviation, L kg^{-1} FPCM	5.5	0.8	6.3
Deviation, %	9.6	6.8	9.1
Low input farm, L kg^{-1} FPCM	54.7	10.7	65.4
Deviation, L kg^{-1} FPCM	-2.6	-1.0	-3.6
Deviation, %	-4.5	-8.5	-5.2

[a] The calculation was based on the biophysical allocation method.

3.2. Water footprint of milk produced in Heilongjiang, California and New Zealand

The average water footprint of milk produced in Heilongjiang was 11 L H_2Oe kg^{-1} FPCM (by biophysical allocation), with 76% occurring in the production of feed (Table 5). This can be interpreted as meaning that the production of 1 kg milk in Heilongjiang had an equivalent potential to contribute to freshwater scarcity as the direct consumption of 11 L of water at the global average WSI. Milk produced in California had a higher water footprint (461 L H_2Oe kg^{-1} FPCM), with relatively high consumptive water use (470 L kg^{-1} FPCM) and high water scarcity. New Zealand milk had the lowest water footprint (0.01 L H_2Oe kg^{-1} FPCM, Table 5).

Table 5. Water footprint of milk produced in Heilongjiang, California and New Zealand at dairy factory gate.

	Heilongjiang, China	California, USA	New Zealand
Blue water consumption [a], L kg^{-1} FPCM	69	470	1
WSI (local) [b]	0.125	0.996	0.011
WSI (national) [b]	0.478	0.499	0.023
Water footprint [a], L H_2Oe kg^{-1} FPCM	11	461	0.01
Feed production, %	76	>95	<5
Dairy farm operation, %	24	<5	>95

[a] Based on data from Asselin (2012) and Zonderland-Thomassen and Ledgard (2012).
[b] Data from Pfister et al. (2009).

4. Discussion

4.1. Water footprint of large-scale dairy farming in China

For large-scale milk production systems in Heilongjiang province, most consumptive water use is associated with feed production and this life cycle stage is the first focus for mitigation. Strategies for reducing consumptive water use might include increasing irrigation water use efficiency in crop production, importing feed from other regions where less irrigation is needed or where local water scarcity is even lower, and increasing feed conversion efficiencies for milk production. Although water consumption associated with other dairy farm activities (e.g. animal drinking water, dairy shed water use and water associated with farm inputs) was small, strategies such as reducing the evaporation and wastage of drinking water and the use of recycled water for cleaning could have additional potential to reduce water consumption.

To appropriately address the environmental impacts of consumptive water use, the local water scarcity where production occurs must be taken into consideration. The water availability footprint of milk produced in Heilongjiang was only 11 L H_2Oe kg^{-1} FPCM, much lower than that of cereals produced in some of China's water-scarce regions (e.g. 367 L H_2Oe kg^{-1} for maize in Huang basin, 931 L H_2Oe kg^{-1} for wheat in Hai basin) (Huang et al. 2012). Although plant and animal-derived products cannot be directly compared because of differing nutritional attributes, these water footprint results illustrate that animal products can have lower environmental impact in terms of water resource depletion than some crop products. Even for the same agricultural commodity, farming systems and local environmental context can differ greatly. When considering a large country, such as China, variation in local water stress can be extreme with WSI values (at the province scale) ranging from 0.02 to 1.00 (calculated using data from Pfister et al. (2009)).

The blue water consumption associated with milk produced in grazing and mixed systems has typically been found to be less than that in industrial dairy systems where all feed components are purchased and there is a greater tendency to rely on irrigated crops (Mekonnen and Hoekstra 2012). In China, the majority of dairy cows are raised in these grazing and mixed farming systems (DAC 2011). In addition, the relatively low water stress in Heilongjiang resulted in the milk products derived from this region having only a modest water footprint. As a general principle, low resource input, predominantly non-irrigated, grass and crop-based livestock production systems have little impact on freshwater resources from consumptive water use. As such, similarly modest water footprint results might be expected for livestock products in many other parts of China and the general assertion that livestock production is a major driver of water scarcity in China should not be hastily accepted. We recommend that the water footprints of dairy and other livestock products produced in the different regions of China should be explored in future research using the LCA approach.

To meet the increasing demand for dairy products, China needs to significantly expand its dairy production. As mentioned in section 2.1, more than 80% of the milk production currently occurs in northern China. Unlike Heilongjiang, some of the other provinces in the north (e.g., Inner Mongolia, Hebei and Shanxi provinces) have regions which are already under serious water stress. Increased water consumption for milk production in these provinces may cause serious environmental impact. Water footprint assessment is therefore essential to guide the sustainable development of China's dairy industry.

4.2. Impact mitigation options for the agri-food industry

Nowadays, many consumers have become more critical and not only wish to be informed about the safety of their food but also its origin and the sustainability of its production (Wognum et al. 2011). Manufacturers in the food sector can respond to these changing consumer demands by implementing strategies to reduce environmental impact and by public reporting of product environmental footprints. This study has highlighted a range of practical interventions for food companies to reduce the negative impacts arising from water consumption in the life cycles of food products with dairy ingredients.

Due to the importance of water consumed in primary production, one approach that food companies can take is to source agricultural ingredients from locations with low water stress and from regions where there is low irrigation water demand. For example, Page et al. (2011) reported the water footprint of tomato grown for the Sydney market in Australia and found that the water footprint of local produce was about 8 times higher than alternative suppliers from other regions. Similarly, the water footprints of beef ranged from 3 to 221 L H_2Oe kg^{-1} at the farm gate between six beef cattle production systems in Australia (Ridoutt et al. 2012). These results illustrate the enormous variability in water footprints that exists and therefore the great potential to alleviate water scarcity through selective procurement of agricultural commodities. In the case of dairy-based confectionary (Huang et al. 2014), dairy ingredients supplied from California, where both the local WSI and irrigation water demands were highest, might be avoided or otherwise highlighted for strategic water footprint reduction initiatives. Another consideration to reduce the water footprint of the dairy-based processed foods might be to source more dairy ingredients from New Zealand or Heilongjiang. That said, for some ingredients, it may be more difficult to change the supply region in the short-term because of the structure and location of the established agricultural industries. The opportunities for impact mitigation in such cases are to source ingredients from farms which have higher irrigation water use efficiency within the region. Investments in farming systems which increase the efficiency of irrigation water use, decrease runoff and increase the productivity of rain-fed production systems should be encouraged. These activities could be driven by the food industry by making water-saving agreements with their suppliers.

4.3. Limitations of this study

This study has been the first application of LCA-based water footprinting in Chinese dairy production. There are several limitations arising from the available data and calculation method. Firstly, the dairy farming subsystem was modeled using data collected from only four dairy farms. Although the sensitivity analysis indicated that the overall findings were not affected by farming system data uncertainty, it remains desirable to expand the sample size in future research and to include additional regions of milk production. Furthermore, this study only assessed consumptive water use in the context of water stress. However, water pollution is also an acknowledged problem in parts of China and in certain cases the dairy sector is implicated (Liu et al. 2004; Wang et al. 2010). It is therefore desirable that future water footprint research of dairy products in China investigate nutrient and other emissions to water in addition to consumptive water use.

The limitation of the water footprint metric is that it focuses on the single issue of water scarcity and is not an indicator of overall environmental sustainability. There are frequent tradeoffs between water consumption, greenhouse gas (GHG) emissions and other sources of environmental impact. For example, tomato production systems in Australia with lower water footprint were also found to have a higher carbon footprint (Page et al. 2012). Actions to reduce water footprints might require more energy use and consequently increase GHG emissions, and interventions to reduce GHG emissions might increase water consumption. Therefore, priorities for overall environmental improvement should be carefully considered.

5. Conclusion

As the first application of LCA-based water footprinting in the dairy industry in China, this study has illustrated that livestock products can be produced with modest potential to contribute to freshwater scarcity. Thus, the generalization that the growing demand for livestock products is the major driving factor for China's water scarcity is not supported in this case. We conclude that it is necessary to examine the regionalized variation in water footprints of all major agricultural commodities as the heterogeneity within sectors is large and the opportunities for water footprint reduction are widespread. This study has demonstrated the large variability in the water footprints between dairy farming systems. As China's domestic milk production is expanding to meet the growing demand, expansion of dairy farming in water-stressed regions should be avoided, unless dairy systems in these areas can predominantly rely on rain-fed crops and pastures. Strategic opportunities also exist for China to reduce its external water footprint associated with dairy products imported from other countries. Food companies can reduce their burden on freshwater systems by sourcing dairy ingredients from regions with low water stress and low water consumption demand. However, interventions to reduce water footprints should not be taken without due consideration given to the potential consequences for other environmental impact categories (e.g. GHG emissions), as well as social and economic factors.

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