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# Water availability footprint of milk and milk products from large-scale dairy production systems in Northeast China

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ABSTRACT

As China's dairy consumption grows, both the domestic milk production and the importation of dairy products are increasing to meet demand. As a first step toward understanding the environmental impacts of water use in the expanding Chinese dairy industry, life cycle assessment (LCA) was used to calculate the water availability footprint for large-scale production systems in Heilongjiang, a major production region. Comparisons were also made with imported products from 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 production in California and New Zealand respectively. Accordingly, the water footprints of milk products (cradle to factory gate) produced in Heilongjiang were much lower than those imported from California, but higher than those from New Zealand. From a food industry perspective, shifting the sourcing of dairy products from California to New Zealand or Heilongjiang could greatly reduce the associated life cycle water footprints of dairy-based processed foods. These results highlight that dairy products can be produced with minimal potential to contribute to freshwater scarcity. However, dairy production systems vary, both in production pattern and local environmental context. With the expansion of dairy farming in China, the development of farming systems with high consumptive water requirements should be avoided in water-stressed regions.



## 1. Introduction

Livestock production has been identified as an important source of humanity's burden on freshwater resources (IDF, 2010; Mekonnen and Hoekstra, 2012) which have been overexploited unsustainably in many parts of the world (UNESCO-WWAP, 2009). 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 been shifting 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 been increasing at an annual growth rate of 16% over the last decade (DAC, 2011). The nation's net imports of dairy products have also expanded to keep up with the domestic demand, with a growth rate in excess of 30% during 2003–2008 (Ma et al., 2011). Expansion of the dairy sector in China has led to serious environmental problems in some cases (Liu et al., 2004; Sun et al., 2010; Wang et al., 2010). Of the various environmental impacts, water depletion is now a serious concern (Mekonnen and Hoekstra, 2012; Singh et al., 2004), and one which has not yet been adequately addressed in the Chinese context.

Dairy farming involves not only direct consumptive water use as drinking and cleaning water for animals, but also indirect water embedded in feed for cattle. In recent years, the water footprint

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metric has been employed as a scientific tool to address water use in relation to human production and consumption. 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 premise that animal products have higher virtual water content than crop products (e.g. 1644 $m^3$ $ton^{-1}$ 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.

As such, environmental relevance, especially the extent to which humanity's consumption and production contribute to water scarcity, 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 water footprint standard is taking (ISO 14046, 2013). Although different models exist to assess global water availability and resulting water stress (Vorosmarty et al., 2000; Alcamo et al., 2003; Hoekstra et al., 2012), they fail to explicitly illustrate the cause–effect relations between water use and environmental relevance. It is very necessary and meaningful to develop methods to address water use in life cycle assessment (LCA) which is the analytical technique used to quantify the various environmental interventions caused by products from cradle to grave (Berger and Finkbeiner, 2010). In many LCA studies, impact assessment on water use has now been performed (Bayart et al., 2010; Mila i Canals et al., 2008; Kounina et al., 2013) and the water stress index (WSI) developed by Pfister et al. (2009) is widely applied as a characterization factor at the midpoint level to describe the environmental impact of freshwater consumption in the life cycle of products and processes. The WSI index was further incorporated into the water footprint schema by Ridoutt and Pfister (2010) to assess the impact of water consumption in relation to the level of water scarcity at the location where the water consumption occurs. Compared to volumetric-oriented indicators such as virtual water, this kind of impact-oriented indicator is recommended as being more revealing for decision making (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.

This study conducted a detailed inventory of life cycle water consumption of dairy production in Northeast China. This occurred as part of an LCA consultancy project for Mars Food (China) Co. Ltd, and the water footprints of milk and milk products of Chinese origin were subsequently compared with those produced in other countries exporting to China. Our purposes were twofold. Firstly, to report the water footprints of milk and milk products produced in China. Secondly, to offer strategic insights to the Mars Company about ways to improve the sustainability of their confectionary products from a consumptive water use perspective. The wider dissemination of results is also intended to increase understanding of sustainable water use in the agri-food sector in China, and especially in relation to the expanding dairy industry.

## 2. Methods and data

### 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. The number of dairy cows increased from 0.64 million head in 1980 to 14.2 million head in 2010 (DAC, 2011). At the same time, there has been a distinct shift in production patterns from household to large-scale dairy farms. The share of large-scale dairy farms (>100 head) was only 12% in 2002, but by 2010 the share had grown to 31% (DAC, 2011). Milk production mainly occurs in northern China, which in 2010 had almost 12 million dairy cows, or more than 80% of the national herd (NBSC, 2011). This study addressed large-scale milk production systems in the north-eastern province of Heilongjiang, which is the second largest province in terms of milk output. In 2010, there were about 2.1 million head of dairy cows and the total raw milk production was 5.6 million tons, accounting for 15% of the total national output (DAC, 2011). This study focused on the southern Heilongjiang region where many large-scale farms are located. 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 and milk products (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) were considered. The consumption of soil moisture derived from natural rainfall (so-called green water) does not generally contribute to regional freshwater scarcity in water bodies and was not included in the calculation. Inventory data were collected to describe the dairy farming subsystem, crop farming subsystems and dairy factory subsystem. The study assessed the production of 1 kg of raw milk, skim milk powder (1% fat, 3.9% water and 34.5% protein) and anhydrous milk fat (99.8% fat, 0.1% water and 0% protein) respectively.

The dairy farming subsystem was modeled using first-hand survey data collected from four large-scale dairy farms and

**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 were presented on a yearly basis, $yr^{-1}$.
[b] Artificial insemination.

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