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Water scarcity footprint of dairy milk production in New Zealand – A comparison of methods and spatio-temporal resolution

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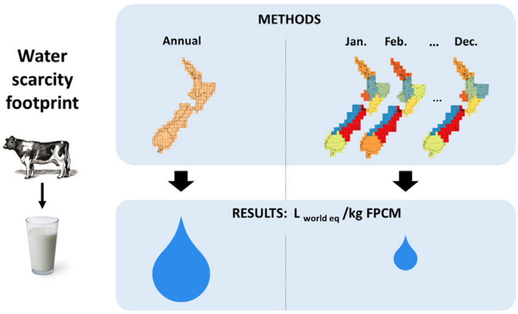
HIGHLIGHTS

- The water scarcity footprint of Waikato milk was lower than Canterbury milk.
- Regional and monthly assessment was compared to country and annual assessment.
- Aggregated characterisation factors overestimated impacts.
- Contribution analysis with AWaRe and Pfister et al. (2009) showed similar rankings.

GRAPHICAL ABSTRACT



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ABSTRACT

Water scarcity footprinting now has a consensual life cycle impact assessment indicator recommended by the UNEP/SETAC Life Cycle Initiative called AWaRe. It was used in this study to calculate the water scarcity footprint of New Zealand (NZ) milk produced in two contrasting regions; "non-irrigated moderate rainfall" (Waikato) and "irrigated low rainfall" (Canterbury). Two different spatial and temporal resolutions for the inventory flows and characterisation factors (CFs) were tested and compared: country and annual vs. regional and monthly resolution. An inventory of all the consumed water flows was carried out from cradle to farm-gate, i.e. from the production of dairy farm inputs to the milk and meat leaving the dairy farm, including all water uses on-farm such as irrigation water, cow drinking water and cleaning water. The results clearly showed the potential overestimation of a water scarcity footprint when using aggregated CFs. Impacts decreased by 74% (Waikato) and 33% (Canterbury) when regional and monthly CFs were used instead of country and annual CFs. The water scarcity footprint calculated at the regional and monthly resolution was 22 $L_{\text{world eq}}$/kg FPCM (Fat Protein Corrected Milk) for Waikato milk, and 1118 $L_{\text{world eq}}$/kg FPCM for Canterbury milk. The contribution of background processes dominated for milk from non-irrigated pasture, but was negligible for milk from irrigated pasture, where irrigation dominated the impacts. Results were also compared with the previously widely-used Pfister method (Pfister et al., 2009) and showed very similar ranking in terms of contribution analysis. An endpoint indicator was evaluated and showed damages to human health of 7.66×10^{-5} DALY/kg FPCM for Waikato and 2.05×10^{-3} DALY/kg FPCM for Canterbury, but the relevance of this indicator for food production needs reviewing. To conclude, this study highlighted the importance of using high-resolution CFs rather than aggregated CFs.

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1. Introduction

Agriculture is a major user of freshwater[1] (WWAP, 2009) and has major effects on water resources, both in terms of consumption and quality degradation. In a context where agriculture has to produce more while saving water, tools are needed to identify environmental hot-spots and mitigation options. Life Cycle Assessment (LCA) is a powerful tool for quantifying the environmental impacts of products (Hellweg and Milà i Canals, 2014). One strength of LCA is its holistic approach, considering the whole life cycle of the product, which is particularly relevant for globalised food production chains. The significant efforts made to improve water footprinting methods in the past few years (Tendall et al., 2013; Kounina et al., 2013), has resulted in the consensual indicator Available Water Remaining (AWaRe) (Boulay et al., 2017). This indicator is in line with the ISO standard for water footprinting (ISO 14046, 2014). AWaRe has been developed by the Water Use in LCA (WULCA) group, and is the midpoint indicator recommended by the United Nation Environmental Program/Society of Environmental Toxicology and Chemistry Life Cycle Initiative (UNEP/SETAC Life Cycle Initiative), for assessing a water scarcity footprint (UNEP, 2016). Water scarcity is the 'extent to which demand for water compares to the replenishment of water in an area, such as a drainage basin, without taking into account the water quality' (ISO 14046, 2014). As a result, water scarcity footprint is a metric that quantifies the potential environmental impacts related to water consumption. Impacts on water quality are addressed by other impact categories such as freshwater eutrophication.

Water consumption is defined as 'the water removed from, but not returned to, the same drainage basin' (ISO 14046, 2014), such as from evaporation or transpiration, and can originate from ground water or rainfall. Note that instead of using the terms of "blue" and "green" water, which do not have hydrological meanings, we will refer to rainfall water, ground water and surface water.

New Zealand (NZ) is the eighth largest milk producing country in the world and the world's leader on the dairy export market since 2013 (Coriolis and MBIE, 2017). The OECD environmental performance review for NZ lists NZ amongst the countries abstracting the most water per capita (OECD, 2017), but this does not acknowledge that part of this water is not consumed (since part will drain to aquifers), and that water is abundant in NZ. Water scarcity footprint is a more relevant metric since it allows connection of water consumption with the local water scarcity. Thus, using a water scarcity footprint metric is important in order to gain insight into water consumption hot-spots along the NZ dairy production chain.

The water scarcity footprint of Waikato and Canterbury milk was calculated in 2012 (Zonderland-Thomassen and Ledgard, 2012), but significant changes in impact assessment models, databases and international guidelines, call for a new assessment using the latest methods. In particular, there is a need for recognition of the importance of spatial variability of water scarcity and to account for temporal variability (Boulay et al., 2017; Pfister and Baumann, 2012). The new AWaRe indicator allows estimation of impacts at a high spatial and temporal resolution. So far, there are only a few milk water footprinting studies using AWaRe; Ridoutt and Hodges (2017) applied it for Australian milk, and Ramos et al. (2016) for Spanish milk. Most milk water footprinting studies have used the Pfister et al. (2009) method, such as De Boer et al. (2013), for Dutch milk, Murphy et al. (2017) for Irish milk and Huang et al. (2014) for milk in Northeast China. The International Dairy Federation (IDF) is calling for more case studies applying AWaRe to dairy products in various geographic locations before recommending this indicator (IDF, 2017).

Additionally, only a few studies extended the assessment of water consumption damages to human health, and none applied the endpoint method recommended by UNEP (2016) to milk; namely the method of Motoshita et al. (2014).

To sum up, there is a need to apply the new consensual indicator for water footprinting to milk produced in different regions of the world. For the sake of comparison with previous studies, this needs to be alongside the widely used Pfister et al. (2009) indicator.

The objectives of this study were to: (i) calculate the water scarcity footprint of NZ milk produced in two contrasting regions "non-irrigated moderate rainfall" (Waikato) and "irrigated low rainfall" (Canterbury), using midpoint and endpoint methods recommended by the UNEP/SETAC Life Cycle Initiative (AWaRe and Motoshita et al., 2014) and recently improved water databases, (ii) assess the effect of different spatial and temporal resolution of inventory flows and characterisation factors, and (iii) compare these results with the previously widely used method of Pfister et al. (2009).

2. Materials and methods

2.1. Water scarcity footprint scope

The functional unit was 1 kg of fat and protein corrected milk (FPCM) at the farm gate in NZ (Waikato or Canterbury region). The whole life cycle required for the production of raw milk was analysed, from the production of dairy farm inputs to products leaving the farm (milk and meat) (Fig. 1). This includes the production of brought-in-feeds (from within NZ and overseas) and their transport to the dairy farm, agrochemicals, seeds, fuel and electricity used on-farm; cows grazing on pasture (including dairy cows and replacement animals); cows milking and farm dairy effluent management. Note that for each brought-in-feed, all inputs such as fertilisers and fuel are also accounted for. This system is producing not only milk, but also meat (from dairy cows, surplus calves and heifers). The allocation of environmental impacts between milk and meat was based on the biophysical approach recommended by the International Dairy Federation (IDF, 2015). The allocation factor for milk was 85.2% for Waikato and 85.5% for Canterbury. The allocation between crop by-products (e.g. palm kernel expeller is a by-product of palm oil) was based on an economic approach (IDF, 2015). In compliance with the ISO 14046 standard for water footprinting, quantities of water used were analysed based on, resource type (precipitation, surface or ground water), form of water use (evaporation, transpiration or product integration), geographical location, and temporal variability when relevant. The water footprint impact assessment methods of Pfister et al. (2009), Boulay et al. (2017) and Motoshita et al. (2014) were calculated using an inventory of surface and ground water consumed.

2.2. Description of New Zealand dairy farms

Milk production relies on year-round grazing of pasture across all NZ. This study focused on milk production in the Waikato and Canterbury-Marlborough (hereafter called Canterbury) regions. The Waikato region is the largest producer of milk with 24.5% of the national production, followed by Canterbury with 23.4% in 2015/2016 (LIC DairyNZ, 2016). With an annual average rainfall over the last 30 years of 1200 mm in Waikato and only 654 mm in Canterbury (Wheeler et al., 2007), the pasture and crops are irrigated in Canterbury, but are not in Waikato.

Data were collected from DairyNZ's DairyBase (http://www.dairynz.co.nz/business/dairybase), and averaged for 156 individual dairy farms in Waikato, and 62 in Canterbury over the 2015/2016 production year. Primary farm data included inputs (e.g. fertiliser, feed), number of animals and milk production. Pesticides used on-farm were based on Manktelow et al. (2005) while feed dry matter (DM) content was based on feed values from DairyNZ (DairyNZ, 2016a).

Table 1 shows the main characteristics of Waikato and Canterbury dairy farms. DM intake was calculated using the New Zealand's

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[1] Note that in this paper freshwater will be referred as water for the sake of brevity.