

Water in an LCA framework – applying the methodology to milk production in Finland

Kirsi Usva^{1,*}, Eetu Virtanen², Helena Hyvärinen¹, Jouni Nousiainen¹, Taija Sinkko¹, Sirpa Kurppa¹

¹MTT Agrifood Research Finland

²University of Helsinki

*Corresponding author. E-mail kirsi.usva@mtt.fi

ABSTRACT

An LCA case study for water-related impacts on milk production in Finland is presented. Non irrigated feed crops were used in this “cradle-to-dairy” system. Impact assessment used methodology developed by Pfister et al. (2009). Result show that 5.75-5.85 liters of consumptive water is used to produce one liter of packaged skimmed milk. Results from previous studies range from about 1-250 l/kg. Drinking water for dairy cattle is the most significant factor in water consumption (44-45%). Also the volumes of washing water on farms and at dairy factories are substantial. Working practices and equipments affect water consumption on dairy farms, and variation among farms is considerable. Characterization factors for Finland differed significantly from the corresponding factors for geographically and socio-economically similar countries with abundant water resources. The characterization factors concerning Finland should be evaluated and developed to enable more accurate assessments of water-related impacts of products.

Key Words: life cycle assessment, water footprint, milk, animal production, environmental impact assessment

1. Introduction

The global water crisis demands that researchers include water issues in environmental impact assessments of products, particularly food products, which represent most of the world’s water consumption. Two evolving methodological frameworks are helping practitioners conserve water resources (Boulay et al. 2013). Originally the water footprint referred to a method developed by Chapagain and Hoekstra (Chapagain et al. 2006, Hoekstra & Chapagain 2007) grounded in the concept of virtual water (Allan 1993, 1997). The evolving ISO Standard ISO/DIS 14046 on water footprint is based on a life cycle assessment (LCA) framework. Both methodologies take account of total direct and indirect water consumption and indicate its relevance (Boulay et al. 2013).

According to Shiklomanov and Rodda (2003), 66% of world water withdrawals and 86% of its consumption are for agriculture. At the local level the share of agriculture is much less in developed countries and in areas with rain-fed agriculture. It also heavily depends on whether imported foodstuffs are taken into account. In Finland agriculture is rain-fed, and the share of agriculture is only 3%, domestic use comprises 25% of water withdrawals and industrial withdrawal is 72% (FAO 2013). Only about 23% of Finland’s freshwater consumption (technically introduced freshwater, “blue water”) is based on national water resources, mostly because of virtual water content of imported foodstuffs (Mekonnen & Hoekstra 2011).

In the future, as a result of population and economic growth, the global demand for freshwater will increase by 40% more than the available water resources (McKinsey 2009). It was forecasted a decade ago (Shiklomanov & Rodda 2003) that in 2025 about 30-35% of the world’s population will live in areas where water availability is very low or catastrophically low, at less than 1000 m³ freshwater annually per capita. The relative water consumption of agriculture is likely to decrease, mostly due to growth in the industrial and domestic sectors. It is expected that by 2025 global withdrawals for agriculture will increase by 25%, for industry by 50% and for the domestic sector by 80% (Shiklomanov and Rodda 2003).

For these reasons everything possible should be done to ensure that food is produced without consuming local scarce freshwater resources in an unsustainable way. In Finland in practice all field crops are rain-fed, irrigation in the open is mainly used only for vegetables and potatoes (Tike 2012). Finland is one of the EU countries with a Water Exploitation Index WEI of less than 10% which is defined as a “no water-stress”-area (EEA 2003). In terms of water consumption, Finland might be a very good area for water-intensive food production. However, some other water-related environmental problems are very serious. In agriculture in Finland water eutrophication is considered worst environmental problem (Niemi and Ahlstedt 2013) and Baltic Sea is considered to be one of the world’s most polluted seas (HELCOM 2007). Because of this, when assessing the environmental impact of food production, it is necessary to consider several water-related problems simultaneously.

In this paper we assess the data availability and quality and also methodological suitability for assessing water-related problems in circumstances of rain-fed agriculture in less used impact categories of water deprivation, and the impacts on human health, ecosystems and resources. We use milk as a case study because milk is, with other animal products, one of the foodstuffs that represent relatively high freshwater consumption during its production chain.

2. Materials and methods

2.1. Milk production system - background

The dairy industry and meat processing are the two main sectors in the Finnish food industry. Dairy products are also the most significant single product group in Finnish food exports, with cheese and butter representing 16% of the total food exports in 2012. Nevertheless, domestic milk consumption exceeds production (Niemi and Ahlstedt 2013). In 2012, still 50% of Finnish dairy cows were kept in tie-stall barns that are gradually being replaced by bigger free-stall barns, as the size of dairy farms increases (ProAgria 2012). More than 80% of Finnish beef production is based on animals originating from dairy herds (MMM 2013).

2.2. System boundary, functional unit and allocation

LCA was used as a framework to assess the water-related environmental impacts of Finnish milk. The system we included:

- feed crop and grass production with agricultural inputs fertilizers, lime, seeds
- industrial feed production
- dairy farms
- dairies, package production and municipal waterworks
- fuel and electricity included in all stages
- transport

Retailers and consumers were excluded from the study.

The functional unit (FU) was one liter of skimmed milk transported from the dairy to the retailer.

Allocation between milk and meat was done according to IDF (2010) methodology for carbon footprint calculation, when the allocation for milk was 87% and for meat 13%. Also allocation between dairy products was done according to IDF methodology, where different weighting factors are provided for electricity, heat, water and raw milk. Raw milk was allocated between dairy products in the basis of the milk solids. (IDF 2010)

2.3. Dairy farm model

Technologies, size of the herd and feed systems vary among dairy farms. We used a dairy farm nutrient management model (Nousiainen et al. 2011) to model fodder consumption in three different sized and technologically different farms (Table 1), where milk production was 8900 kg per dairy cow per year and dairy cow live weight 600 kg (ProAgria 2010). Feeding was based on grass silage, rape seed meal, and either home-grown grain from the farm or a commercial feed. Energy consumption in different farm types was based on figures from the literature (Posio 2010; Edström et al. 2005).

Table 1. Farm types in dairy farm model.

	Farm type 1	Farm type 2	Farm type 3
Technology	Tie-stall dairy barn, pipe milking	Free-stall dairy barn, milking parlor	Free-stall dairy barn, 2 voluntary milking robots
Animals	25 dairy cows, 10 heifers, 9 calves	60 dairy cows, 24 heifers, 22 calves	120 dairy cows, 48 heifers, 42 calves
Feed	Grass silage, own grain and rape seed meal OR Grass silage, commercial feed and rape seed meal	Grass silage, own grain and rapeseed meal OR Grass silage, commercial feed and rape seed meal	Grass silage, own grain, commercial feed and rape seed meal

We modeled all farm types for Southern, Northern, Eastern and Western Finland and combined farms according to statistics to average regional milk production from different sized farms (Table 2). Regional raw milk goes to a dairy located in the same region. Input-output data for different dairies was obtained from the dairy in question. Average Finnish milk production was modeled in relation to size of different dairies. The share of commercial feed (BIF) feeding regime was assumed to be used in 75% of total milk production and on-farm produced feed (OFPF) in 25%, based on expert opinion (Nousiainen 2014, personal communication).

Table 2. Farm types in four regions in Finland (Tike 2012)

	25 dairy cows	60 dairy cows	120 dairy cows
Southern Finland	69%	24%	7%
Western Finland	69%	24%	7%
Eastern Finland	73%	21%	6%
Northern Finland	71%	25%	4%

2.4. Feed production

According to the 2010 Finnish Agricultural Census (Tike 2012) the irrigated area was 0.07% for cereals, 0.03% for turnip rape and rape, and 0.2% for grasses (of the total crop area). The results from the 2010 census support the findings from earlier reports (Pajula and Triipponen 2003; Pajula and Järvenpää 2007) based on expert opinion. The only imported component in the dairy cattle feed concentrate was rapeseed meal, which originates from the Baltic countries (personal communication Raisio 2013), where rape is not generally irrigated (FAO 2013). Applying irrigation in Finland would result in bigger and better quality yields, but irrigation is profitable only in horticulture and for special crops. Irrigation in the open thus represents a marginal share of the water consumption in Finland (Tike 2012). In this study we assumed that no irrigation is applied in the Finnish milk production system.

Fuel consumption in crop cultivation was based on literature (Mikkola and Ahokas 2009). Water consumption in commercial feed production is based on data from industrial feed plant (Raisio 2013, personal communication).

2.5. Drinking water

Several formulas for exist estimating of drinking water intake in dairy cows. The most applicable for Finnish conditions was chosen by comparing the estimate given by a formula and the measured water intake values from the experiment of Kuoppala et al. (2004). The equation presented by Castle and Thomas (1970) had the closest values. It has also very easily measurable parameters (Eq. 1).

$$\text{Drinking water intake (kg/day)} = - 15.3 + 2.53 \times \text{milk (kg /day)} + 0.45 \times \text{diet dry matter content (\%)} \quad \text{Eq.1}$$

Water requirements of growing cattle are often expressed as total water intake, for example in McDonald et al. (1988). In this study, environmental temperature was assumed to be 16 °C, so the total water intake of calves less than 6 weeks of age was assumed to be 7.5 kg/kg DM intake and in older cattle 5.75 kg/kg DM intake. The feed water was calculated according to the dry matter content of a typical diet and drinking water by difference.

2.6. Washing water in dairy farms

The average types of machinery and equipment of the three different farm models were assessed based on the Finnish dairy herd recording system (ProAgria 2012). The database covers approximately 75% of Finnish dairy farms.

Water consumption in conventional pipeline milking systems in tie stall barns was assessed based on expert opinion (Mäki et al 2005). Milking parlors and automatic milking in free stall barns were assessed on the basis of Danish measurements (Rasmussen and Pedersen 2004, Lindgaard Jensen 2009) and on Swedish expert opinion (Gyllenswärd 2011). The sizes of the farm tanks and their wash water consumption and other water consumption in milk storage premises was assessed based on various expert opinions (Nyman 2013, personal communication; Korhonen 2013, personal communication and Gyllenswärd 2011). Other wash water consumption for different farm types was estimated on the basis of building regulations (MMM 2012) and German expert information (KTBL 2008).

2.7. Data sources in processing phase

2.7.1. Dairies

Water consumption data are based on data acquired from three dairies representing the entire dairy sector in Finland. Water consumption data include all freshwater consumption in dairy. Consumption includes milk truck washing. Energy consumption data (electricity and heating) were also based on dairy data.

2.7.2. Package production

Regular skimmed milk is sold in Tetra Rex cartons. We estimated the water consumption of package production on the basis of the Stora Enso Skoghäll mill water footprint case study (Stora Enso 2011), for which the water consumption was 6 m³ / tonne liquid packaging board. The inventory result is 0,164 l water / FU for a Tetra Rex carton.

2.7.3. Waterworks

Municipal waterworks produce water of which on average 18% is uninvoiced (Finnish Water Utilities Association 2012). Uninvoiced water includes water use by the fire department and other municipal use. The amount of unused water due to leakage and pipeline breaks varied according to site. Specific data from waterworks in those sites were used. Water losses in pipelines were calculated only for dairies and water losses in actual dairy sites were 12-15%. Dairy farms were assumed to acquire their water from their own well (Sorvala et al. 2006).

2.8. Other data sources

For electricity, fossil fuel production, fertilizers and lime we used inventory data from EcoInvent v. 2.2. Cooling water and water use in turbines for energy production were excluded. Diesel consumption for wood chips and peat production was assessed according to Mälkki and Virtanen (2003), Jylhä (2013) (wood) and Uppenberg et al. (2001) (peat).

2.9. Impact assessment

Environmental impact of freshwater was assessed according to a method developed by Pfister et al. (2009). Damage in three areas of protection was calculated: human health, quality of ecosystem and resources. Damage assessment was carried out according to Eco-indicator-99 assessment framework (EI99) (Goedkoop et al. 2001).

Because production was located mostly in Finland and only minor parts in Baltic countries (rapeseed as part of the bought-in feeds), and no irrigation was used in rapeseed production, the same characterization factors were used for each phase in the production chain.

2.9.1. Water stress index and general impact

Water stress is defined by the ratio of total annual freshwater withdrawals to hydrological availability (WTA). The water stress index (WSI) determines the portion of consumptive water used which dispossess other users of freshwater. In the methodology developed by Pfister et al. (2009, Supporting Information), water stress indices for countries range from 0 to 1. WSI for Finland is relatively high at 0.416. At the watershed level most of Finland gets low WSI values, with some exceptions in the Varsinais-Suomi region, in some islands in the Gulf of Finland and in the Helsinki area. According to Pfister (written communication 2014) high total value in Finland is mostly due to water deficiency problems in the Helsinki area in 1960s and 1970s. Since then the problem has been solved by piping water from an external watershed to the Helsinki area.

Global average WSI (0.602) was used in the water footprint (general impact) calculations. The amount of consumptive water was normalized by dividing by 0.602 and expressed in H₂O equivalents (H₂Oeq).

2.9.2. Impacts on human health

For human health the pathway for water shortages for irrigation resulting in malnutrition is included in the method (Pfister et al. 2009). The Human Development Index (HDI) is an important part of the characterization factor $\Delta\text{HH}_{\text{malnutrition}}$ for human health. HDI is at high level (> 0.88) for Finland, and as such would cause $\Delta\text{HH}_{\text{malnutrition}}$ to be zero. There are rivers flowing from Finland to Russia and therefore the cross-boundary watersheds need to be included and CF for $\Delta\text{HH}_{\text{malnutrition}}$ for a country is calculated by counting up the watershed level results. The total CF for $\Delta\text{HH}_{\text{malnutrition}}$ for Finland is $4.4\text{E}-05$ [10^{-6} DALY/m³] (Pfister et al. 2009). Districts adjacent to Finland in Russia (Leningrad area, Republic of Karelia and Murmansk area) are developing, but still the HDI were in all of them < 0.88 in 2013 (UNDP 2013).

2.9.3. Impacts on ecosystem

For places where plant growth is water-limited, withdrawals of so-called blue water may finally reduce the availability of green water and decrease vegetation and plant diversity. CF for ecosystem quality ΔEQ is $1.62\text{E}-01$ [m²·yr/m³] for Finland (Pfister et al. 2009).

2.9.4. Impacts on resources

The renewable annual water resource in Finland is 106 km³ (Shiklomanov & Rodda 2003) and total freshwater withdrawal 1.485% of actual renewable water resources (ARWS) (FAO 2013). In Sweden the corresponding percentage for ARWS is 1.503% (FAO 2013). The characterization factor for damage to resources in Finland is $7.42\text{E}-03$ [MJ/m³] and zero for Sweden (Pfister et al. 2009). According to Pfister (2014, personal communication) this is due to same artifact as the relatively high WSI for Finland. For that reason, CF for water resource impact (ΔR) should be zero and the impact on the resource is insignificant. Because of this, and also because there are only few relatively small areas with high WSI in Finland, and dairy production is located mostly in low WSI areas, we used a CF of zero for ΔR .

3. Results

3.1. Water consumption in production chain

Freshwater consumption for production of one liter of skimmed milk was 5.775 liters. In different feed regimes the results were 5.85 liters for cattle using on-farm grain in feed (OFPF) and 5.75 liters for cattle using commercial fodder as part of their feed (bought-in feed, BIF). The most water consuming phases were animal drinking (44-45%), water use in dairies (23-24%) and washing on the dairy farm (15-16%). Other water consumption in primary production included feed production, energy use and transportation and it comprised 6-7% of total use. Other water consumption in processing was respectively 9-10% and included package production, energy use in dairy, transportation and uninvoiced water in municipal waterworks.

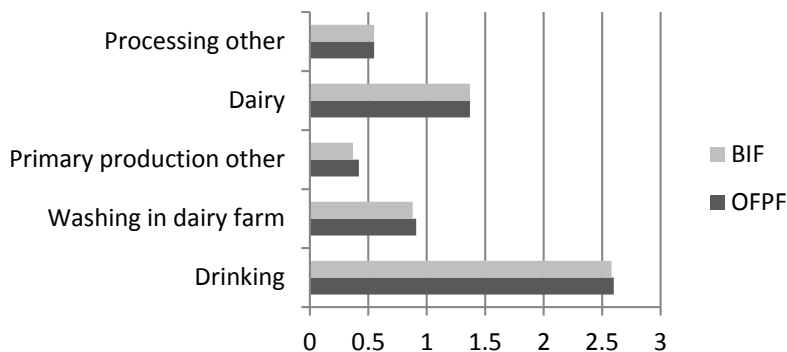


Figure 1. Total consumptive use of freshwater in production of skimmed milk ($\text{liter}_{\text{water}} / \text{liter}_{\text{milk}}$) in production systems for on-farm produced feed (OFPF) and bought-in feed (BIF).

Dairy farm water consumption without drinking water was 1.25-1.33 liters/FU. Total water consumption from cradle to farm-gate was varying from 4.36-4.89 liters/FU. Washing the milking machines consumed most of the total amount without drinking water (Figure 2). Water consumption in feed production consisted of water consumption in agricultural input production (fertilizers, lime, fuels, electricity and seeds). After allocation in dairy-phase the total consumption from cradle to farm-gate was 3.8-3.9 liters/FU.

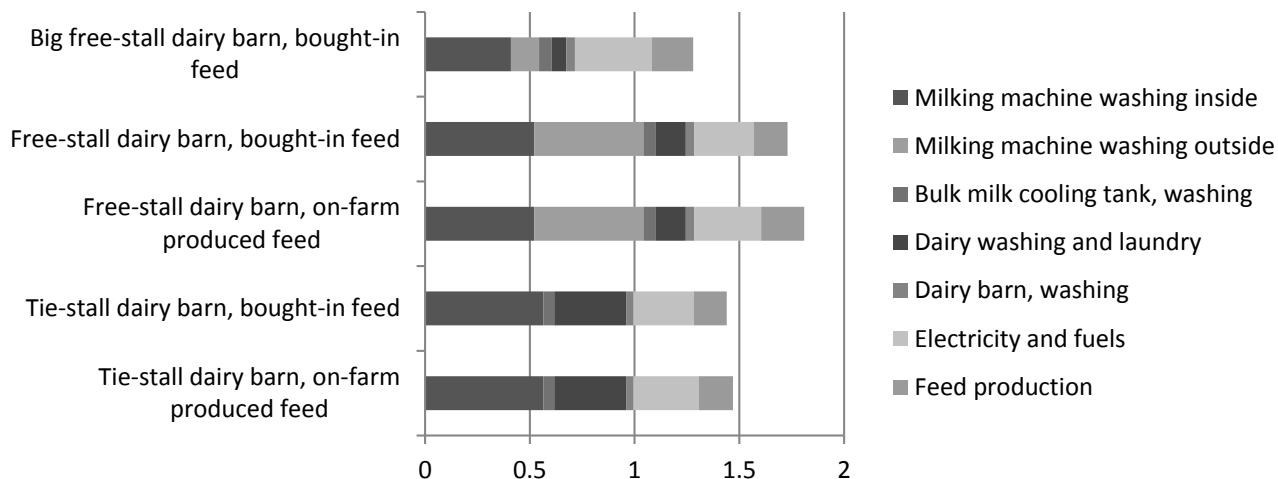


Figure 2. Consumptive use of freshwater in primary production without drinking water ($\text{liter}_{\text{water}} / \text{liter}_{\text{milk in dairy farm gate}}$).

3.2. Impact assessment results

Impact assessment results were calculated in four impact categories (Table 3). Impact on resources was assumed to be zero (see 2.8.4). If calculated with current characterization factors, the impact would be $4.3E-05$ MJ/l_{milk}.

Table 3. Impact assessment results for one liter of skimmed milk.

Consumptive use l/l milk	Water deprivation H ₂ Oeq/l milk	Ecosystem quality ΔEQ m ² *year / l milk	Human health $\Delta HH_{\text{malnutrition}}$ DALY / l milk	Resources ΔR MJ / l milk
5.8	4.0	9.4E-04	2.5E-07	0

4. Discussion

4.1. Discussion of the results

Consumptive water use in milk production based on rain-fed feeds was 5.8 liters / liter skimmed milk. Drinking water for dairy cattle, water consumption in dairies and washing waters on farms were the most significant factors included in total consumptive water. Differences between feeding regimes are negligible in this case. Milking machine type makes a minor difference between farm types, but due to data quality no further conclusions are possible to draw about farm type differences. Numerical results indicate that total consumptive water use in milk production is low and water-related impacts are not in very high level in Finland.

The improvements in methodology (discussion in 4.4) might even decrease the impact assessment results in the future. However, in terms of other water-related impacts, dairy sector in Finland is considered to have high eutrophication impact: in Baltic Sea agriculture constitutes the largest share of the reported total diffuse nutrient loads to the sea (HELCOM 2011).

4.2. Comparisons with other studies

Worldwide water-related impacts of milk production have been studied by several researchers (i.e. Netherlands: De Boer et al. 2013, Australia: Ridoutt et al. 2010, New Zealand: Zonderland-Thomassen, M.A. and Ledgard, S.F. 2012). As shown in Table 4, results vary considerably. This is partly due to different local characterization factors, and as such, indicates the different impacts at various localities.

Production systems are very different, especially regarding irrigation, which affects results significantly. Irrigated feeds were used in the Netherland and New Zealand/ Canterbury cases. In the Netherland the consumptive water use was 66.4 liters in total, but only 5.7 liters without feeds. In New Zealand there was almost a 250-fold difference between the Waikato, with rain-fed feed production, and Canterbury cases.

However, there are several definitions for consumptive water. In New Zealand cases the consumptive water does not include all water withdrawn but water a) withdrawn and then evaporated, b) water returned to another catchment and c) water integrated in a product (see Table 4) (Zonderland-Thomassen, M.A. and Ledgard, S.F. 2012). Other studies include drinking water and irrigation water, if used, in total (De Boer et al. 2013, Australia: Ridoutt et al. 2010), and therefore it is not meaningful to compare the amount of consumptive water.

A huge variation in inventory data also affects the results, especially regarding the amount of water consumption on dairy farms, which varies considerably. In the New Zealand cases, the drinking water was 50 liters / lactating cow / day, in our study 73 liters and in Australia 150 liters. Milk production, feed dry matter and temperature have the biggest impact on cow water intake, and that probably explains the differences.

Table 4. Impact assessment results from previous studies on milk production from cradle to farm-gate. Milk produced by bought-in feed (BIF) in tie-stall dairy barn is used here as an example of Finnish milk.

Study milk from cradle to farm-gate	Consumptive use l/l, milk	Water footprint ³ H ₂ Oeq /l, milk	Ecosystem quality ΔEQ m ² *year / l milk	Human health ΔHH _{malnutrition} DALY / l milk	Resources ΔR MJ / l milk
Finnish milk	4.52 ¹	3.12	7.32E-04	2.0E-07	0
De Boer et al. 2013 Dutch milk	66.4 ¹	33.4	1.29E-2	8.0 E-08	6.7E-3
Ridoutt et al. 2010 Australian milk powder	14.1 ¹ (milk) 108 ¹ (milk powder)	1.9 (milk) 14.4 (milk powder)	-	-	-
Zonderland-Thomassen, M.A. and Ledgard, S.F. 2012 New-Zealand milk a) case Waikato	0.945 ²	0.165 ⁴	5.86E-05	0	0
b) case Canterbury	249.3 ²	11.1 ⁴	3.06E-02	0	0

¹consumptive water includes drinking water and irrigation water, if used, as a whole

²consumptive water according to Water Footprint Network (Hoekstra et al. 2009, 2011) includes water withdrawn and then evaporated, water returned to another catchment and water integrated in a product

³Water footprint according to Ridoutt et al. (2010)

⁴blue water abstracted

Finnish milk seems to be associated with rather low consumptive water use. However, water footprint is higher than in Australia and New Zealand Waikato, because of the high WSI for Finland. Human health impacts exist, according to the method of calculation, in Russia. Both of these results are significantly affected by CF.

In general the huge variation in results from different studies indicates that the method of calculation is yet not completely established. Because of the local characteristic of water-related problems, it is natural that variation among inventory data is considerable. However, some differences may be due different definitions of consumptive water, different methods of data collection and also in cases of less-qualified data, as in this study (see 4.2), the likelihood of error increases. In addition to different inventory data sets in different studies, there might be differences in system boundaries and allocations. At the moment researchers have still only very few previous studies to compare with their own results.

4.3 Data availability

Good quality inventory data were not always available during inventory analysis. Data variations in other milk studies indicate this situation is not unusual, even though part of the variation is due to natural differences in production systems. Dairies measure their total water consumption, but no product-specific or production-line-specific data were available and therefore allocations were necessary. Water consumption in dairy farms had to be assessed by reviewing the literature thoroughly and canvassing expert opinion. There were some published data on water consumption using specific milking equipment and other equipment, but most studies used as data sources focused on research questions other than freshwater consumption. This definitely had a negative impact on data quality in this context.

Many dairy farms have their own well and no water meter making the assessment of water consumption a challenging task. Because it seems that in many cases that water consumption on dairy farms is very variable, depending on machine control and special practices, e.g. in frequency of washing, a more comprehensive study with rigorous consumption measurements would give interesting information.

4.4. Methodological gaps

4.4.1. System boundaries and allocation

The definition of consumptive water use seems to be very important question in terms of system boundary definition. Irrigation and animal drinking water are the most important phases of the milk production chain, and the results are different when in those phases all water withdrawals are included in inventory or only evaporated water, water returned to another catchment and water integrated in a product. Similar questions arise also in other phases of the production chain.

Municipal waterworks are not very often included in freshwater consumption inventory studies. We noticed that leakage of freshwater in pipelines has an impact, especially when the pipelines are long, and should be included in inventories. Another interesting case is the products of mining industry: lime and K- and P-fertilizers. There is always rainwater flowing into the mine and there is a need to pump it out. Should this water be included into the study or not? In some cases water is clean and available for many purposes like in lime mining, but not in all cases.

In terms of allocation, milk chain is a pretty complicated chain. At the moment a proper method for allocations in water related issues is missing. IDF (2010) recommends raw milk allocation in dairy in the basis of milk solids in climate change impact category, but regarding to water-issues, this should be re-assessed.

4.4.2 Impact assessment

Currently there are characterization factors that are defined using global models, but enhanced modeling tools for regionalized life cycle impact assessment are needed (Pfister et al. 2009). In this study we saw how global models may lead to misinterpretations at the local scale, as discussed in 2.8. In Finland, WSI and CF especially should be assessed again using up-to-date local data for impact their impact on the resource base. Also CF for impact on human health should be redefined, and good data should be found to detail the real impact pathway better to establish if there are connections between health impacts in Russia and water withdrawals in Finland.

5. Conclusion

As a first approach to apply LCA framework to food stuff in Finland, focusing on less used impact categories of water-related impacts, this study provides basic knowledge about suitability of the current methodology and data in this kind of assessments.

Impacts of water consumption in milk production were calculated, but further studies are needed to draw conclusions about water deprivation, human health and water resource impacts. At least WSI and CF for Impact on Resources should be redefined for Finland, using up-to-date local data instead of global models. Human health impact is due to the lower HDI in Russia, which affects the calculation, but there might be reasons to reassess the impact pathway.

Globally, variation in water-related impacts of milk production systems is huge due to location of production and i.e. production type (irrigated versus rain-fed agriculture) and the first thing to do is to point out hotspots of the production chains and magnitude of impacts. LCA framework is well suitable for assessing the consumptive water of food stuffs. We found out that consumptive water of milk production, in Finland, is relatively low. At the moment weaknesses in methodology and CFs based on global models are setting limitations for the impact assessment as well as poor quality of the data. Therefore, both a) improvements in methodology and b) more experience in water-related impacts included in LCA to gradually improve quality and quantity of the data are necessary. LCA is a strong tool to show several impact category results at once and to provide suitable quantitative information for improving the sustainability of the production chains, also when water-related impacts are in question.

Acknowledgments

We thank for Stephen Pfister and Marlies Zonderland-Thomassen for helpful discussions.

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This paper is from:

Proceedings of the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector



8-10 October 2014 - San Francisco

Rita Schenck and Douglas Huizenga, Editors
American Center for Life Cycle Assessment

The full proceedings document can be found here:
http://lcacenter.org/lcafood2014/proceedings/LCA_Food_2014_Proceedings.pdf

It should be cited as:

Schenck, R., Huizenga, D. (Eds.), 2014. Proceedings of the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector (LCA Food 2014), 8-10 October 2014, San Francisco, USA. ACLCA, Vashon, WA, USA.

Questions and comments can be addressed to: staff@lcacenter.org

ISBN: 978-0-9882145-7-6