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Water footprint of beef cattle and sheep produced in New Zealand: water scarcity and eutrophication impacts

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ABSTRACT

There is increasing recognition of the tension between livestock production and freshwater availability. Changes in freshwater availability can be generated by both freshwater consumptive and freshwater degradative use. Agriculture is a major water user, and beef cattle and sheep farming is an important agricultural activity in New Zealand (NZ). This study assessed potential environmental impacts associated with water use in beef cattle and sheep farming in NZ, following a water footprint method compliant with life cycle assessment principles with a focus on the water scarcity footprint and eutrophication potential (EP) impacts. The life cycle required for the production of beef cattle and sheep was analysed cradle-to-farm-gate, excluding animal transport or processing. Survey data from Beef and Lamb New Zealand for the year 2009/10 were used to cover a range of beef cattle and sheep farm types throughout NZ (426 farms averaged in seven farm classes), and water scarcity footprint and EP weighted averages were calculated for beef cattle and sheep. The normalised NZ weighted average water scarcity footprint of beef cattle of 0.37 L H_2O-eq/kg LW was lower than the published normalised values for the water scarcity footprint of beef cattle produced in Australia (3.3–221 L H_2O-eq/kg LW) and in the UK. Also, the NZ weighted average water scarcity footprint of sheep of 0.26 L H_2O-eq/kg meat (assuming that 40% LW was converted into meat) was lower than the water scarcity footprint of sheep meat reported for the UK (8.4–23.1 L H_2O/kg meat).

Blue water losses associated with evapotranspiration from irrigated pasture comprised the greatest proportion of the total water scarcity footprint, despite the small areas of farmland irrigated. The weighted average EP of beef cattle was 51.1 g PO_4-eq/kg LW, and the weighted average EP of sheep was 26.1 g PO_4-eq/kg LW. The NZ weighted average EP for beef cattle was lower than the 105 g PO_4-eq/kg LW reported for European Union suckler beef cattle. On-farm nitrate leaching and phosphorus runoff dominated the EP. From an international marketing perspective, beef cattle and sheep produced in NZ have a potential advantage by having low water scarcity footprints compared to some non-NZ pastoral farming systems due to their production efficiencies and low annual water-stress levels. The impact of NZ pastoral farming on freshwater availability can potentially be reduced by practices that decrease water use, increase feed conversion efficiencies, increase the use of non-irrigated feed supplements, and reduce irrigation. The indicator EP was chosen to enable comparisons with non-NZ studies, but gaseous emissions of nitrogen compounds contributed 33–40% of the total, and their contribution to water pollution is uncertain. This study highlighted the need for a harmonised methodology and as well as to consider specific local contextual information when interpreting the absolute and relative implications of EP results, for example by developing NZ-catchment-specific characterisation factors for aquatic eutrophication in future studies.

1. Introduction

Global livestock production has a major challenge in contributing to global food supply without increasing adverse environmental effects (Godfray et al., 2010). There is increasing recognition of the tension between livestock production and water use and quality (Mekonnen and Hoekstra, 2012; Ridoutt et al., 2012a;

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Zonderland-Thomassen and Ledgard, 2012). The actual or potential adverse effects of water use by agricultural production are issues common to many countries (Mekonnen and Hoekstra, 2010a,b). Also, water availability can be limited in certain areas and seasons (Pfister et al., 2009). New Zealand (NZ) has been identified as a country with relatively low annual water stress levels (Pfister et al., 2009; Herath et al., 2010). However, during summers with low rainfall, NZ farmers in many regions experience limited water availability, either because of reduced stream flows, reduced groundwater levels, water restrictions or lack of irrigation water availability (MfE, 2006). Dairy production has become a dominant component of NZ agriculture in the past two decades, but beef cattle and sheep farming is still significant, with red meat and related products contributing NZ$5.6 billion, or nearly 13%, of NZ's total export revenues in 2011 (Beef + Lamb NZ, 2012). Many consumer markets are placing a premium on positive environmental profiles of products, and water footprinting is developing as an important means of providing comparable information. It is therefore important that NZ red meat suppliers are prepared with information on the water footprint of their products. This will enable them to make meaningful comparisons, understand the potential for reducing their water footprint, and potentially achieve a comparative advantage over products from other countries. Therefore, a need was identified to assess resource use and/or potential environmental impacts related to water use associated with beef cattle and sheep production.

Several approaches exist for assessing a water footprint, of which the Water Footprint Network (WFN) method developed by water resource management scientists (Hoekstra et al., 2011) and water footprint approaches developed by life cycle assessment (LCA) scientists (e.g., Bayart et al., 2010; Ridoutt and Pfister, 2010, 2013) dominate this area (Jefferies et al., 2012). The ISO 14046 standard for water footprinting that is under development will be compliant with LCA principles.

Both water quantity and water quality degradation should be considered when assessing the impacts of water use in LCA, because changes in freshwater availability can be generated by both consumptive and degradative use of freshwater (Bayart et al., 2010). Water scarcity as an indicator of freshwater consumptive use, can be assessed by using the method developed by Pfister et al. (2009). This method has already been applied to several farm case studies (Ridoutt et al., 2012a,b). Water quality degradation as an indicator of freshwater degradative use, can be partially illustrated with the eutrophication impact category. How to account for full water quality impacts in water footprint studies is still under development (Boulay et al., 2011), whereas farm case studies already exist in which the eutrophication potential (EP) has been assessed (e.g. Nguyen et al., 2010; Thomassen et al., 2008).

The goal of this study, therefore, was to assess potential environmental impacts associated with water use in beef cattle and sheep farming in New Zealand, following a water footprint method compliant with LCA principles and focusing on water scarcity and eutrophication impacts.

2. Material and methods

2.1. Systems analysed

New Zealand red meat (beef from beef cattle, lamb meat from sheep <1 year old and mutton from sheep ≥1 year old) is derived from beef cattle and sheep that are commonly raised together under a variety of production systems across a range of climatic conditions. To deal with this variation in production systems, survey data from 426 farms throughout NZ were collected and each farm was categorised into one of seven farm classes. Data were collected between July 1st 2009 and June 30th 2010 (the official financial year for NZ farms referred to as the year 2009/2010 in this study) (Beef + Lamb NZ, 2013). The farm data, averaged for each farm class, were used to calculate a weighted average water scarcity footprint and EP of beef cattle and sheep by accounting for the contribution of each farm class to the total net amount of beef cattle or sheep live weight (LW) leaving the farm gate before processing into meat. Beef from culled dairy cows was excluded, although the proportion of beef coming from culled dairy cows in NZ is over 20% (Beef + Lamb NZ, 2012).

Average total effective land area in pasture (i.e., excluding that in forest, bush and other non-grazed areas) across the seven farm classes ranged from 245 ha (class 7 South Island intensive finishing) to 8872 ha (class 1 South Island high country) (Table 1). The average combined beef cattle and sheep stocking rate in stock units (SU; equivalent to one 55 kg ewe producing one lamb, which equates to consumption of 600 kg Dry Matter (DM)) per hectare ranged from 1.1 (class 1) to 10.6 (class 7). A small amount of irrigation was applied in farm classes 1, 2, 6, and 7 in the South Island only, varying from 55 mm/irrigated ha in farm class 7–425 mm/irrigated ha in farm class 1 (Table 1). The estimated area of land under irrigation

Table 1
Characteristics of the seven beef cattle and sheep farm classes in New Zealand for the year 2009/10 (Beef + Lamb NZ, 2013).[a]

Characteristic	S.I. high country	S.I. hill country	N.I. hard hill country	N.I. hill country	N.I. intensive finishing	S.I. finishing breeding	S.I. intensive finishing
	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7
Farms in survey (n)	19	34	61	140	72	64	36
Farm area, ha	8872	1693	782	419	269	478	245
Total SU[b]/ha	1.1	3.8	7.9	8.8	9.2	7.9	10.6
Rainfall, mm	688	742	1140	1500	1188	771	1071
Irrigated pasture, ha	49[c]	21	–	–	–	7	1
Irrigation, mm	425	290	–	–	–	185	55
Feed supplements, kg DM[d]/ha	0.4	1.5	0.04	0.4	1.4	9.7	18.1
N fertiliser, kg N/ha pasture	2.7	9.3	4.1	8.5	15.4	10.2	12.5
P fertiliser, kg P/ha pasture	11.2	13.8	17.4	22.2	20.5	17.2	20.8
kg LW[e] beef/SU	32.1	33.6	27.9	26.7	12.7	45.3	35.5
kg LW sheep <1 yr old/SU	12.7	27.5	21.6	26.8	30.9	36.1	40.1
kg LW sheep ≥1 yr old/SU	6.7	8.1	8.2	7.4	7.3	8.7	9.6

[a] S.I. = South Island, N.I. = North Island.
[b] One New Zealand Stock Unit (SU) is equivalent to one 55 kg ewe rearing one lamb, equating to intake of 600 kg DM/year. One beef cattle corresponds to about 3–6 SU depending on live weight and growth rate.
[c] 60% of the farms in Marlborough/Canterbury and 50% of the farms in Otago applied irrigation during 120 days on 1% of total area (0.55*0.01*8872).
[d] Dry matter.
[e] Data refer to kg live weight (LW) sold from the farm.

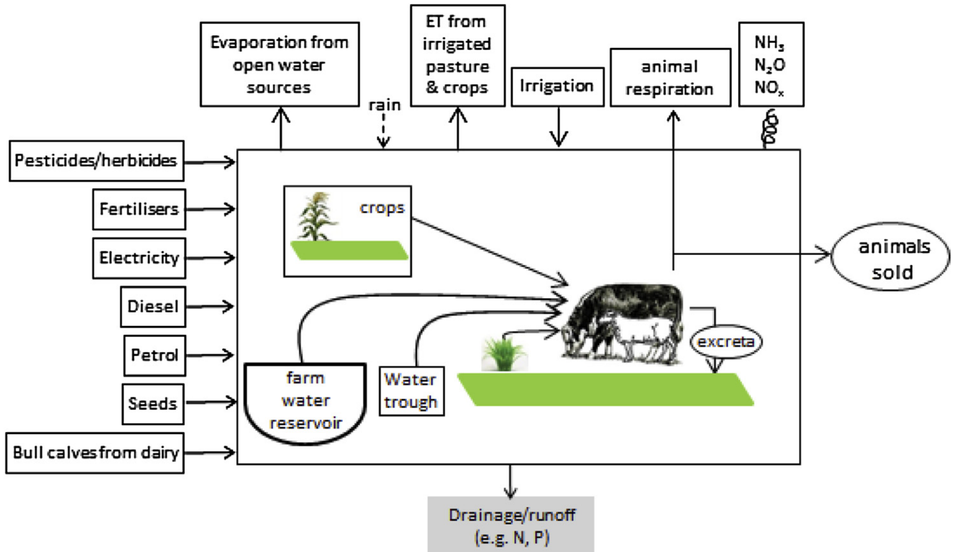

Fig. 1. System boundaries and water consumption and nutrient sources for the life cycle inventory of New Zealand beef cattle and sheep farming (ET = evapotranspiration) gaseous emissions to the air.

for these farm classes was based on data provided by Beef and Lamb NZ (2013). This information covered the percentage of farms within the farm class that applied irrigation, the type of land (pasture only for all analysed farm classes, since no crops were irrigated), irrigated area (% of land area), and number of irrigation days.

The predominant source of feed for beef cattle and sheep was grazed pasture. Low levels of forage crops grown on-farm (averages ranged from 0.04 kg DM/ha in farm class 3–18.1 kg DM/ha in farm class 7) were fed to the animals to overcome pasture shortages in summer or winter and to optimise production. Average nitrogen (N) fertiliser rates varied from 2.7 to 15.4 kg N/ha/year of pasture area (Table 1), while the average phosphorus (P) fertiliser rate varied from 11.2 to 22.2 kg P/ha/year of pasture area. The average LW sold per SU based on beef cattle ranged from 12.7 to 45.3 kg LW, while the average sheep <1 year old LW sold per SU based on sheep ranged from 12.7 to 40.1 kg LW (Table 1).

Fig. 1 shows the system boundaries of the analysed beef cattle and sheep farming systems. The life cycle required for the production of beef cattle and sheep was analysed from the production of inputs to animal LW leaving the farm gate, i.e. excluding transport or processing of animals into meat.

2.2. Functional unit and allocation method

Within an LCA study, choice of the functional unit and choice of allocation method can have a huge impact on the final outcome. The functional unit reflects the main output of the studied system. This was defined as one kg of beef cattle LW or one kg of sheep LW, which was also differentiated into one kg of sheep <1 year old LW (sold as lamb meat after processing) and one kg of sheep ≥1 year old LW (sold as mutton after processing).

Allocation method refers to the partitioning of environmental impacts within a multifunctional process. Several multifunctional processes were present in the system under study including the joint production of cattle and sheep leaving the farm gate and the co-production of sheep meat and wool. Water footprints at the farm level were allocated between the animal types (sheep and cattle) according to their biological function. This utilised an energy-based animal intake model to estimate feed DM intake for each animal type (Clark et al., 2003). For the co-production of sheep meat and wool, economic allocation was used (based on five-year 2005–2009 average farm revenues from the products) (Table 2).

2.3. Water scarcity footprint

The method proposed by Pfister et al. (2009) was applied to calculate the impact associated with blue water[1] consumption from beef cattle and sheep farming on water availability; equivalent to the stress-weighted water footprint in Zonderland-Thomassen and Ledgard (2012). Blue water consumption was assessed as a function of freshwater scarcity considering hydrological conditions. The annual water stress index (WSI) from Pfister et al. (2009), based on a withdrawal-to-availability ratio, was used as a characterisation factor. This WSI is calculated as a logistic function of the ratio of total annual freshwater withdrawals to hydrological availability, while accounting for monthly variability in precipitation as well as for watersheds with strongly regulated flows. The Beef + Lamb NZ survey provided numbers of beef cattle and sheep per region, which enabled the differentiation of the WSI between beef cattle and sheep within each farm class; the resultant 14 WSIs ranged from 0.010 to 0.013 (Table 3). These WSIs are all below 0.2 and can therefore be considered low water-stress regions (Pfister et al., 2009).

The NZ average WSI value of 0.021 was applied to processes which occurred throughout NZ (e.g., electricity, diesel, and petrol) or with unknown locations. However, region-specific WSI values were applied when specific data were available, e.g., in the case of pasture/crop seeds, which were produced mainly in the Canterbury region. No normalisation was used, which means that the total water scarcity footprint was not divided by the global average WSI value of 0.602.

2.4. Eutrophication potential (EP)

To assess the main potential water quality impacts resulting from beef cattle and sheep farming, EP was determined. The impact

[1] Blue water is defined as freshwater available in surface water bodies (e.g., rivers and lakes) and aquifers (Falkenmark and Rockström, 2006).

Table 2
Biophysical allocation values when dividing the environmental impact between beef cattle and sheep, and economic allocation values when dividing the environmental impact between wool, sheep <1 year old (sold as lamb meat after processing), and sheep ≥1 year old (sold as mutton after processing), of the seven beef and sheep farm classes in New Zealand for the year 2009/10.

Allocation (%)	S.I. high country	S.I. hill country	N.I. hard hill country	N.I. hill country	N.I. intensive finishing	S.I. finishing breeding	S.I. intensive finishing
	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7
Beef cattle vs. Sheep:							
Beef cattle[a]	0.21	0.30	0.37	0.42	0.54	0.26	0.05
Sheep[a]	0.77	0.69	0.62	0.56	0.45	0.72	0.95
Sheep products:							
Wool[b]	0.58	0.25	0.20	0.18	0.15	0.18	0.15
Sheep <1 year old[b]	0.20	0.65	0.60	0.68	0.74	0.75	0.82
Sheep ≥1 year old[b]	0.22	0.11	0.20	0.14	0.11	0.07	0.03

[a] Biophysical allocation based on energy intake.
[b] Economic allocation based on farm revenues from products using a five year average (2005–2009).

assessment method CML 2001 of Guinée et al. (2002) was chosen to enable comparisons with non-NZ beef cattle and sheep studies. However, this method does not distinguish between terrestrial and aquatic eutrophication. EP is expressed in phosphate equivalents (PO_4^{3-}-eq) using multiplication factors of PO_4 1, NO_3 0.1, N_2O 0.27, NO_x 0.13, NH_3 0.35, and chemical oxygen demand (COD) 0.022. Loss of COD to waterways was excluded because it was considered negligible as no manure is collected (all outdoor grazing systems) and animal excreta does not usually enter waterways directly. While it is recognised that P loss is the most significant nutrient affecting surface water quality, evaluation of NZ waterways has revealed that N is also a key (and sometimes the major) determinant of water quality in many surface waterways (McDowell and Lynard, 2008).

2.5. Inventory

As water consumption within LCA is a relatively new research area, secondary data were used whenever primary data were not available. In the following sections the inventory for both the water scarcity footprint and EP is outlined for the main processes.

2.5.1. Water flows and nutrient transport at farm level

Blue water consumption was estimated from evaporation from open drinking water sources (troughs and reservoirs), vapour losses through animal respiration, and evapotranspiration (ET) of irrigation water from pasture (only for farm classes 1, 2, 6 and 7, where irrigation was applied; Table 1).

The number of water troughs was estimated for each farm class in each region using expert opinion. The number of paddock subdivisions per farm was estimated and one water trough per paddock was assumed; this resulted in estimates ranging between 14 water troughs per farm in farm class 4 and 66 troughs in farm class 1.

Evaporation factors from open water (844 L/m^2/yr for the North Island and 1081 L/m^2/yr for the South Island) were derived from Herath et al. (2011) and were multiplied by the mean surface area of a water trough (1.8 m^2).

For farm classes 3 and 4, water reservoirs (mean area of 200 m^2) were considered important water supplies and were assumed to deliver 55% of the total water supply. Pan evaporation within the associated regions was estimated (NIWA, 2013) and multiplied by 0.8 to correct for pan size, since evaporation from farm reservoirs came from water bodies larger than pans (Ham, 2007).

Vapour losses through animal respiration were calculated using an animal-balance approach which accounts for drinking water intake, water intake from feed, water output in dung and urine, and water content of animals sold from the farm. Thereafter, these respiratory vapour losses were ascribed to blue water according to the proportion of animal water loss from drinking water plus ET from irrigated feed intake relative to non-irrigated feed intake.

Water losses associated with ET from irrigated pasture, as well as drainage and runoff estimates and N leaching and P runoff (from all dissolved and soil-adsorbed sources), were predicted with the hydrological and nutrient cycling sub-models of the OVERSEER® nutrient budget model (Wheeler et al., 2003). The OVERSEER® hydrological sub-model estimates ET, drainage and runoff, and accounts for latitude, temperature regime, rainfall patterns, irrigation, and soil water-holding characteristics. It also accounts for

Table 3
Relevant annual water fluxes and nitrogen (N) in drainage and phosphorus (P) in runoff estimates at the farm level for each farm class predicted using the hydrological, N leaching and P runoff sub-models in the OVERSEER® nutrient budget model (Wheeler et al., 2003).

	S.I.[a] high country	S.I. hill country	N.I. hard hill country	N.I. hill country	N.I. intensive finishing	S.I. finishing breeding	S.I. intensive finishing
	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7
Blue-water evapotranspiration from pasture, mm/ha irrigated	115	68	0	0	0	145	42
Drainage, mm	183	212	503	493	457	210	390
Runoff, mm/ha	55	0	315	153	88	0	17
N leaching, kg N/ha/yr	3	5	11	11	9	7	12
P runoff, kg TP[b]/ha/yr	0.1	N/A	1.3	1.0	0.4	N/A	0.3
WSI[c] beef cattle	0.0121	0.0127	0.0104	0.0104	0.0103	0.0128	0.0109
WSI sheep	0.0121	0.0124	0.0103	0.0104	0.0102	0.0123	0.0109

[a] S.I. = South Island, N.I. = North Island.
[b] Total Phosphorus.
[c] Water Stress Index: Each farm class covered multiple regions. An average WSI for each region was estimated. The survey provided animal numbers for beef cattle and sheep which enabled the calculation of an animal-specific WSI per farm class.

Table 4
Water consumption and data sources of the main inputs in the Life Cycle Inventory stage.

Input	Unit	Water consumption[a]	Source
Pesticides	L H_2O/kg ai[b]	0.25	Calculated using ecoinvent 2.2 database within SimaPro 7.3.3, ReCiPe (Goedkoop et al., 2009), and Shiklomanov and Rodda (2003)
Herbicides			
-Phenoxy	L H_2O/kg	9.2	
- Sulphonylureas		15.9	
- Other hormone types		15.6	
Artificial fertilisers			
- Urea	L H_2O/kg N	1.14	Calculated using ecoinvent 2.2 database (Althaus et al., 2007)
- Single Superphosphate	L H_2O/kg P	37.1	within SimaPro 7.3.3, ReCiPe (Goedkoop et al., 2009)
- Di-Ammonium Phosphate		2.62	
- Potassium Chloride	L H_2O/kg K	1.28	
- Lime	L H_2O/kg	0.005	
Electricity	L H_2O/kWh	13.7	Herath et al. (2011); Hoekstra et al. (2011); Gerbens-Leenes et al. (2009a,b)
Diesel	L H_2O/L	1.2	McDevitt et al. (2011)
Petrol	L H_2O/L	2.0	Jefferies et al. (2012)
Transport[c]	L H_2O/tkm	0.097	Calculated using ecoinvent 2.2 database, ReCiPe (Goedkoop et al., 2009), Shiklomanov and Rodda (2003)
Seeds	L H_2O/kg	84.7	Calculated using OVERSEER® (Wheeler et al., 2003)
Bull calves from dairy[d]	L H_2O/animal	1921	Calculated using Muir et al. (2003) and Ledgard et al. (2008) within SimaPro 7.3.3

[a] Values refer to Life Cycle Inventory, i.e., impact assessment is excluded.
[b] Active ingredient.
[c] Purchased animals, fertilisers.
[d] Compilation of water consumption associated with the use of colostrum, calf milk replacer, cereal meal, electricity, and transport of the animals.

risk of N and P loss, as affected by form of N or P fertiliser and timing of application. Of the four farm classes in which irrigation was applied, blue-water ET from pasture was highest in farm class 6 (145 mm/irrigated ha/yr) and lowest in farm class 7 (42 mm/irrigated ha/yr) (Table 3). The estimated N leached was highest in farm class 7 (12 kg N/ha/yr), whereas the total phosphorus (TP) runoff was highest in farm class 3 (1.3 kg TP/ha/yr).

Data on animal numbers, live weights and wool production were entered into OVERSEER® to estimate feed intakes for beef cattle and sheep from each farm class (Wheeler et al., 2003). Feed quality data (metabolisable energy (ME), digestibility and N concentrations) were accounted for on a monthly basis for all supplementary feed used in addition to pasture. It was assumed that all supplementary feed was produced on the same farm (Fig. 1). DM intake by animals was estimated on a monthly basis by calculating the energy required to meet assumed levels of animal performance (MJ ME per day) and dividing this value by the energy concentration of the diet consumed (MJ ME per kg DM). These feed intake estimates as well as the N concentration in feeds and N captured in products were used to calculate N excretion. Ammonia (NH_3) volatilisation occurs from N excreted in dung and urine, as well as from applied artificial N fertiliser (Ledgard, 2001). It was assumed that 5% of the N excreted in urine was volatilised and 3% from the N excreted in dung, whereas 12% was volatilised from N applied as urea fertiliser and 5% from N applied in non-urea fertilisers (Black et al., 1985; Jarvis and Ledgard, 2002).

Direct N_2O emissions from excreta deposited on pasture and from applied N fertiliser were calculated using specific NZ emission factors corresponding to the fraction emitted to the atmosphere as N_2O (De Klein et al., 2003; Luo et al., 2009). Direct N_2O emissions from forage crop residues and pasture residues associated with pasture renewal were calculated using the IPCC default methodology (2006). Indirect N_2O emissions from NH_3 and N leaching losses from excreta-N and fertiliser-N were calculated using the IPCC-NZ N source and emission factors (MfE, 2012).

2.5.2. Inputs

On-farm herbicide use was estimated by combining weed and pest control expenditure data per farm class from the B + LNZ survey with average NZ herbicide active-ingredient use (Manktelow et al., 2005). On-farm insecticide use (to control sheep intestinal parasites was estimated by combining the number of sheep per farm class from the B + LNZ survey with average NZ insecticide active-ingredient use based on a survey conducted on 92 NZ farms (Reid, 2007). Blue water consumption associated with the use of petrol, fuel for aerial application of fertilisers, truck and car transport of animals, artificial fertilisers, veterinarians, shearers were based on the ecoinvent 2.2 database using SimaPro 7.3.3 software (Table 4). First, abstracted water was calculated by using the midpoint impact category 'Freshwater Depletion' within the impact assessment method ReCipe and assuming that 15% of the abstracted water was evaporated (which is in the range of 5-20% in Shiklomanov and Rodda, 2003). These estimates are proposed as the best estimate available in the absence of more complete information (Table 4).

Blue water consumption associated with diesel production was derived from a NZ-specific study (McDevitt et al., 2011). The EP associated with energy carriers, insecticides and herbicides (phenoxy, sulphonylureas, and other hormone types) were based on the ecoinvent 2.2 database using SimaPro 7.3.3 software, using the CML 2001 impact assessment method (Guinée et al., 2002).

Blue water consumption associated with fertiliser production was calculated by totalling water evaporated from industrial cooling plus ground and surface water transferred to another catchment (Althaus et al., 2007). The EP associated with fertiliser production was based on an LCA of fertilisers applied in NZ farming (Ledgard et al., 2011).

It was assumed that the energy sources for electricity used were equivalent to the NZ national mix, with about 57% of the electricity coming from hydropower (MED, 2010). The average blue water consumption of hydropower generated in 17 stations throughout NZ calculated by Herath et al. (2011) was used. For the other relevant electricity sources from a water scarcity footprint perspective (Hoekstra et al., 2011), blue water consumption of biomass sources was derived from Gerbens-Leenes et al. (2009a,b) and of geothermal power plants from Milà i Canals et al. (2009, 2010).

Purchased seed was used for pasture renewal. Over 75% of land for ryegrass and white clover seed production in NZ was irrigated, and most seed was grown in the Canterbury region (Chynoweth et al., 2010). The OVERSEER® model was used to estimate ET associated with seed production. The estimated renewed pasture area was based on data in the B + LNZ survey on new grass area and oversown areas using a sowing rate of 16 kg grass seed/ha and 2 kg clover seed/ha.

The B + LNZ survey provided information on the number of bull calves from dairy systems entering the sheep and beef cattle farming system per farm class. This number varied from 0 (farm classes 1 & 7) to 73 (farm class 5). An inventory for bull calf rearing in dairy systems was composed (Table 4), which included the amount of colostrum, calf milk replacer and cereal meal fed, as well as data on electricity and transport (Muir et al., 2003; Ledgard et al., 2008).

3. Results

3.1. Water scarcity footprint

The weighted average water scarcity footprint of beef cattle was 0.22 L H_2O-eq/kg LW (Table 5). Blue water losses from the grazed system were low, and consequently the main losses of blue water were associated with bull calf rearing (54%) and blue water ET from irrigated pasture (35%; Fig. 2). The contribution of blue water losses associated with fuel use, seeds, fertilisers, herbicides, animal respiration, and ET from irrigated crops was negligible (<1%). The weighted average water scarcity footprint of sheep (i.e. after allocating for wool) was 0.10 L H_2O-eq/kg LW, of which blue water ET from irrigated pasture contributed most (85%). The variability in water scarcity footprint of beef cattle and sheep between farm classes was large (Fig. 3). The water scarcity footprint of beef cattle and sheep was highest in farm class 1, mostly because of the relatively large extent of irrigation applied to pasture (Table 1). The water scarcity footprint of beef cattle, however, was also high in farm class 5, where no irrigation was applied. This was caused by the relatively large number of bull calves from the dairy system entering this farm class and the large water scarcity footprint associated with the production of milk powder used to feed these calves.

The weighted average water scarcity footprint of sheep ≥1 year old was 0.08 L H_2O-eq/kg LW, whereas the water scarcity footprint of sheep <1 year old was 0.11 L H_2O-eq/kg LW (Table 3). For both animals, blue water ET from irrigated pasture contributed most to the water scarcity footprint (91% and 88%, respectively), despite the small areas of land irrigated on farms (Table 1).

3.2. Eutrophication potential

The weighted average EP of beef cattle was 51.1 g PO_4-eq/kg LW (Table 5). On-farm N leaching and P runoff dominated the EP (60%). Gaseous emissions at the farm level (mainly N_2O, NH_3, NO_x) associated with cattle excreta deposition on pasture and fertiliser

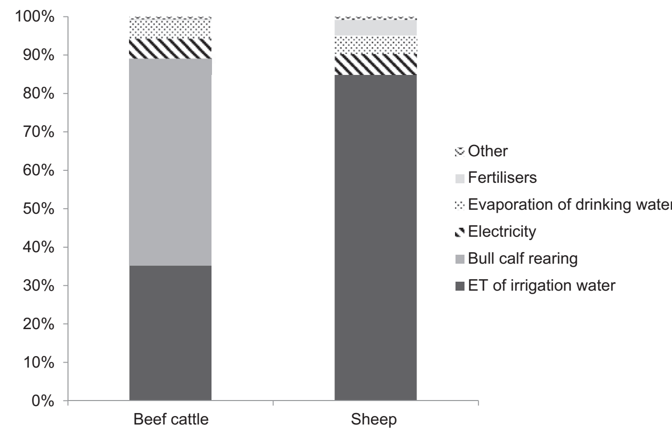

Fig. 2. Contribution of production processes to the water scarcity footprint of beef cattle and sheep (ET = evapotranspiration).

application contributed 38% of the total EP. The weighted average EP of sheep was 26.1 g PO_4-eq/kg LW. Again, on-farm N leaching and P runoff dominated the EP (60%), while gaseous emissions associated with sheep excreta and fertiliser contributed 39% of the total EP.

The variability in the EP of beef cattle and sheep between the farm classes was large (Fig. 4). The EP of beef cattle was highest in farm class 5 due to the relatively high N leaching (resulting from a high stocking density and relatively high use of N fertiliser) and the lowest beef cattle production/ha (Table 1). The EP of sheep was highest in farm classes 1 and 3. Farm class 1 had the lowest N and P losses but also had the lowest stocking rate (Table 1). The EP of beef cattle and sheep was lowest in farm class 6, which had the highest productivity (e.g., the highest beef cattle production in kg LW per SU).

The weighted average EP of sheep > 1year-old and <1 year-old was 19.4 and 28.0 g PO_4-eq/kg LW, respectively (Table 3). For both products, on-farm N leaching and P runoff contributed most (67% and 59% respectively) followed by gaseous emissions at the farm level (33% and 40% respectively).

4. Discussion

4.1. Variability between farms

The results showed large variability in the water scarcity footprint and EP of beef cattle and sheep between the farm classes,

Table 5
The weighted average water scarcity footprint and eutrophication potential (EP) of beef cattle, sheep (average, and distinguished between sheep ≥1 year old, and sheep <1 year old).

Indicator	Animal	Unit	Value
water scarcity footprint	Beef cattle	L H_2O-eq/kg LW[a]	0.22
	Sheep		0.10
	≥1 year old		0.08
	<1 year old		0.11
EP	Beef cattle	g PO_4-eq/kg LW	51.1
	Sheep		26.1
	≥1 year old		19.4
	<1 year old		28.0

[a] Data refer to kg live weight (LW) sold from the farm.

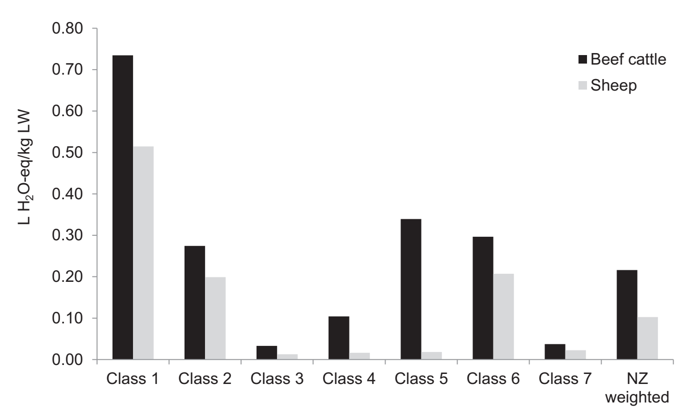

Fig. 3. Water scarcity footprint (L H_2O-eq/kg live weight) of beef cattle and sheep produced by seven farm classes in New Zealand (NZ) for the year 2009/10 (as in Table 1) and their weighted average.

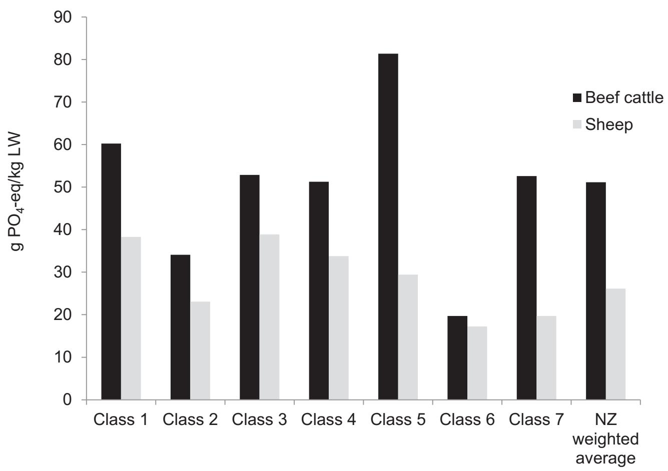

Fig. 4. Eutrophication potential (g PO_4-eq/kg live weight) of beef cattle and sheep produced by seven farm classes in New Zealand (NZ) for the year 2009/10 (as in Table 1) and their weighted average.

which can be attributed to site and management factors. The water scarcity footprint of beef cattle from farm classes 3 and 7 was lowest. In farm class 3, no irrigation was applied, although bull calves purchased from dairy farms had a relatively high water scarcity footprint contribution. In farm class 7, no bull calves from dairy farms were purchased, and a minimal level of irrigation was applied.

The water scarcity footprint of sheep from farm classes 3, 4, and 5 was lowest because there were no blue water losses associated with ET from irrigated pasture since no irrigation was applied. However, farm class 7 also had a low water scarcity footprint but used some irrigation, albeit an average of only 55 mm/ha over only 1 ha during 120 days of the year. In farm class 7, the impact of irrigation on the water scarcity footprint was countered by the high productivity (LW sold/ha) of this intensive finishing farm (i.e., 497 kg sheep-LW/ha) and a high stocking rate (10.6 SU/ha).

Overall, beef cattle and sheep produced in NZ regions with sufficient rainfall, and consequently low annual WSIs (farm classes 3 and 4 and for sheep also farm class 5), had the lowest water scarcity footprints, as did beef cattle and sheep produced in the highly productive farm class 7. Beef cattle and sheep farming in farm class 1 with a low stocking rate had an above-average water scarcity footprint, because of irrigation practices in the Marlborough, Canterbury and Otago regions which have relatively high WSIs. Potential mitigation options were identified after considering the contribution analysis (Fig. 2). Farm management practices that can reduce the water scarcity footprint include 1) producing beef cattle and sheep in regions with low water-stress levels; 2) implementing water-use-efficiency practices in irrigated regions, such as using crops with high water-use efficiency or using precision irrigation (farm classes 1, 2, 6, and 7); 3) reducing the number of bull calves from dairy farms entering beef cattle and sheep farms; and 4) improving productivity or feed conversion efficiency into LW, such as reducing the time to animal slaughter. However, some of these practices may increase other environmental impacts (e.g., bull calves from European dairy farms have a lower carbon footprint than those from traditional beef cattle farms; Nguyen et al., 2010). Thus, it is desirable to consider a range of environmental indicators rather than focus solely on one indicator, in other words, to perform a 'full' LCA.

The EP of beef cattle and sheep was lowest in farm class 6. This farm class had the highest beef cattle production (kg LW per SU; Table 1), with moderate N leaching and no P runoff per ha (Table 3). Besides a focus on increasing production efficiency, the best farm management practice from an EP perspective is to improve nutrient management (McDowell and Nash, 2012) to reduce nutrient leaching and runoff (Ledgard et al., 2009), for example, by applying robust Nutrient Management Plans (LEP, 2012) and using the optimum rate, form, and timing of N and P fertilisers.

4.2. Marketing perspective: results in an international context

With the increased consumer demand for environmental product information such as eco-labelling (Solér, 2012) and potential incorporation of water scarcity footprint and EP information on product labelling in certain markets (for example, in France, following the "Grenelle II" law (Cros et al., 2010)), it is important for the red-meat sector to know how the water scarcity footprint and EP of NZ beef cattle and sheep relate to those from other countries.

Few studies using equivalent methodology on beef cattle and sheep water scarcity footprint have been reported in the international literature. The WF of Australian beef cattle produced in six different geographically defined production systems varied from 3.3 to 221 L H_2O-eq/kg LW (Ridoutt et al., 2012a), which were significantly higher than the NZ weighted average water scarcity footprint of beef cattle (0.37 L H_2O-eq/kg LW after normalisation using the global WSI of 0.602 for comparability), mainly because Australia has higher water stress levels (Pfister et al., 2009). Also, in this Australian study the use of abstracted water rather than consumptive water associated with the production of non-agricultural inputs in the inventory would have led to a slight overestimate.

The water scarcity footprint of Australian lamb produced in Victoria (589 L H_2O-eq/kg LW in Ridoutt et al., 2012b) was higher than the NZ weighted average water scarcity footprint of lamb (0.18 L H_2O-eq/kg LW after normalisation using the global WSI of 0.602 for comparability), which was mainly influenced by the local water scarcity in the Australian regions where farming and feedlot operations occurred. In the Australian system, there was no irrigation of pasture or crops fed directly and only minor irrigation was used on some concentrate ingredients fed in the feedlot. Evaporation losses associated with drinking water due to extensive use of dams was the main hotspot for the WF of Australian lamb (86% in Ridoutt et al., 2012b), whereas evaporation losses associated with pasture irrigation was the main hotspot for the water scarcity footprint of NZ lamb (88%). Assuming that 40% of beef cattle and sheep LW is meat (NZ Beef Council, 2001), the NZ weighted average water scarcity footprint of beef and sheep meat (0.54 and 0.26 L H_2O-eq/kg meat, respectively) was considerably lower than the water scarcity footprint of beef and sheep meat to the farm-gate produced in the UK (15.1–20.0 and 8.4–23.1 L H_2O-eq/kg meat, respectively, depending on production system; calculated using values in EBLEX (2010) and WSI values provided by T. Hess, Cranfield University, UK). The annual WSI of NZ regions where livestock was produced varied from 0.01 to 0.013, whereas the spatially averaged WSI for the UK was 0.27. Because the distribution of livestock in the UK was not uniform, however, the WSI for beef cattle weighted according to livestock production was 0.19 (T. Hess, personal communication).

The low water scarcity footprint of NZ beef cattle and sheep illustrates the benefits of production in regions with low water stress from a resource-efficiency perspective and could highlight a possible marketing advantage.

The NZ weighted average EP for beef cattle of 51.1 g PO_4-eq/kg LW is lower than the 105 g PO_4-eq/kg LW estimated using the same calculation procedure for European Union suckler beef cattle from Nguyen et al. (2010). However, the values for the latter study were based on potential nitrate and phosphate leaching estimates in the inventory stage, rather than on validated model estimates as for NZ. The NZ weighted average EP for sheep of 26.1 g PO_4-eq/kg LW was similar to the average of 31 g PO_4-eq/kg LW for Swedish lamb (Wallman et al., 2012), when adjusted to the same system boundary. However, the latter study excluded the indirect contribution from N_2O emissions and used a different allocation methodology with greater allocation to non-meat co-products. Both the NZ weighted average water scarcity footprint and EP of beef cattle are higher than those of the NZ weighted average of sheep (Table 5).

4.3. Chosen methodology and challenges ahead

From a consumer information and eco-labelling perspective, water footprints of products need to be comparable in a global market context, which highlights the importance of a harmonized approach. The ISO 14046 standard for water footprinting is underway, and therefore the choice of indicators was based on this LCA approach. Also, Zonderland-Thomassen and Ledgard (2012) concluded after exploring multiple water footprint methods, including the WFN approach, that only indicators with a focus on blue water and including an impact assessment were suitable to assess potential impacts on freshwater availability. They also argued that these should be complemented by indicators which assess potential water quality impacts. Kounina et al. (2013) reviewed multiple midpoint and endpoint impact assessment methods, and recognized that the water withdrawal-to-availability ratio characterised in this study as WSI, is a representative proxy for scarcity. However, they question if this water scarcity indicator refers to any potential impact. They suggest that clear evidence of the link between water scarcity and impact on different areas of protection is needed.

Ridoutt and Pfister (2013) argued that for communication purposes, there are advantages in combining the water availability indicator and water quality indicator into one single score using so-called endpoint modelling. Although we have previously applied this approach to NZ dairy farming (Ridoutt et al., 2012c), we were unable to explore this approach in this study, because limited data were available for beef cattle and sheep farms to assess ecotoxicity impacts and no impact assessment method is available to assess ecotoxicology impacts at the midpoint stage. Also, background data of this endpoint modelling approach on water quality impacts needs improvement to better account for differences between countries and catchments.

The focus on only water scarcity and eutrophication impacts, is a limitation of this study, because other impacts on water, such as ecotoxicity, also exist. This study is limited with regards to the completeness of the water footprint profile Also, the results do not enable identification of potential pollution transfers because other impact categories such as global warming potential are not considered.

To enable comparison with non-NZ products, focus was placed on the well-known midpoint indicator EP using the impact assessment method CML 2001 (Guinée et al., 2002). However, the contribution of gaseous emissions to total EP was large (33–40%), which results in interpretation issues. While the incorporation of gaseous forms of N may be appropriate in some countries, these compounds have a minimal contribution to nutrient loading of freshwater in NZ due to low emissions from extensive outdoor grazing systems and lack of industry (e.g., Ledgard et al., 1999). While the need for international harmonisation of a water footprint methodology is acknowledged, it must be stressed that predictions of impacts on water quality by the CML 2001 impact-assessment methodology and others such as ReCiPe (Goedkoop et al., 2009) which differentiates between marine and freshwater eutrophication, need to be better validated. Therefore, to better account for nutrient-based water quality impacts, the development of catchment-specific characterisation factors for aquatic eutrophication is needed.

From a water-use-efficiency perspective, it could be argued that abstracted water ('water withdrawal') is better understood than water consumption by many lay end-users. However, from a hydrological perspective, the actual water lost (e.g., evaporated) from the catchment is of fundamental importance. Herath et al. (2013) suggest using a hydrological water-balance assessment to evaluate the impact on groundwater by considering recharge through drainage, which can reduce the WF significantly. Applying this approach to beef cattle and sheep farming resulted in groundwater recharge in the farm classes where irrigation was applied (Zonderland-Thomassen et al., 2012).

From a resource-management perspective, the real challenge is how to develop comparable indicators that also provide a robust indicator of catchment/region-specific water resource management effects (Jefferies et al., 2012; Perry, 2011).

Multiple indicators have been developed from different disciplines, but eco-labelling requires a harmonised approach. The challenges which the water footprinting community faces are 1) how to integrate the different disciplines (e.g., LCA, water-resource management, hydrology) into one approach that is relevant and understandable to multiple end-users and 2) how to use and integrate catchment-specific information to develop a robust water footprint for products that is relevant for eco-labelling in both a catchment/regional and global context.

5. Conclusions

This study presents the first water footprint of NZ beef cattle and sheep farming using a life cycle approach and data for specific farm classes. The results indicate that from an international marketing perspective, beef cattle and sheep produced in NZ have a potential environmental marketing advantage due to having lower water consumption than those from pastoral farming systems in other countries that have also been studied with LCA. The results of this study illustrate that the impact of NZ pastoral farming on freshwater availability can be reduced by practices that decrease water use, increase feed-conversion efficiencies, increase the use of non-irrigated feed supplements, and reduce irrigation. Similarly, this study highlights that the potential impact of NZ pastoral farming on water quality can be reduced by efficient nutrient management. This study also identified the need for a harmonised methodology and to consider specific local contextual information when interpreting the absolute and relative implications of EP results, for example by developing NZ catchment-specific characterisation factors for aquatic eutrophication in future studies.

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