Indirect water demand of dairy farm buildings

K. Döring[1*], S. Kraatz[1], A. Prochnow[1,2], K. Drastig[1]

(1. *Institute for Agricultural Engineering, Max-Eyth-Allee 100, 14469 Potsdam, Germany;*
2. *Faculty of Agriculture and Horticulture, Humboldt-University of Berlin, Hinter der Reinhardtstr. 8-18, 10115 Berlin, Germany*)

Abstract: Water is needed in agriculture not only to ensure plant growth and to feed livestock, but also indirectly in pre-chains to produce machines, equipment, buildings and operating materials. This water is referred to as indirect water. The focus of this article is on the indirect water demand for farm buildings in milk production, which was assessed for the first time. Four standardized barn types for dairy cows, a young cattle barn, a calf barn, and storage facilities were investigated. The materials and masses of each building type and equipment were determined. The water needed in the process of material production was taken from the Ecoinvent database. The indirect water demand for livestock houses ranges from 1.4 to 1.9 m³ animal place^{-1} yr^{-1} and varies marginally between barn variants. For calf houses and young cattle houses, indirect water demand ranges from 0.3 to 0.8 m³ animal place^{-1} yr^{-1}. The demand for indirect water for technical equipment ranges from 0.2 to 0.7 m³ animal place^{-1} yr^{-1}. The indirect water demand for storage ranges from 0.01 to 0.5 m^3 m^{-3} yr^{-1}. Related to milk production, the indirect water demand is with 0.3 L kg^{-1} milk negligibly low.

Keywords: indirect water, consumptive water, livestock buildings, pre-chains, Germany

Citation: Döring K., S. Kraatz, A. Prochnow, and K. Drastig. 2013. Indirect water demand of dairy farm buildings. Agric Eng Int: CIGR Journal, 15(4): 16−22.

1 Introduction

Water is essential for all life and for agricultural production. With the growing world population and increasing food consumption, water demand is increasing worldwide. Agricultural management and agricultural research are challenged to ensure food security by making efficient use of water resources.

A lot of research has been done in recent years on estimating water use in agricultural production (Berger and Finkbeiner, 2010). Various approaches include the Water Footprint concept (Hoekstra and Hung, 2005), the concept of livestock water productivity (Haileslassie et al., 2009; Descheemaeker et al., 2010), and Life Cycle Assessments (LCA) (Milá i Canals et al., 2009, Milá i Canals et al., 2010; Pfister et al., 2009).

Received date: 2013-10-29 **Accepted date:** 2013-11-19
*** Corresponding author: K. Döring,** Institute for Agricultural Engineering, Max-Eyth-Allee 100, 14469 Potsdam, Germany. Tel. +49 331 5699-857 Fax +49 331 5699-849. Email: kordula.doering@atb-potsdam.de.

To estimate the water demand of goods and services, not only direct water flows but also indirect water flows from pre-chains have to be considered (Blackhurst et al., 2010). With regard to agricultural production, this covers water needed for the production of farm buildings, machinery and technical equipment, as well as farm inputs. Although pre-chains are considered in LCA, e.g., for energy and greenhouse gases (ISO 14040, 2006; Wiedmann and Minx, 2008), this has rarely been done for water so far. One exception is de Boer et al. (2012), who accounted for the water used for inputs such as purchased diesel, gas, electricity and fertilizer.

This study aims at improving the data basis for the inventory analysis of water use in dairy farming. The objective of this paper is to assess the amount of indirect water demand for the construction of dairy farm buildings, storage facilities and technical equipment. Therefore a volumetric approach which does not cover an impact assessment has been chosen. The amount of indirect water is related to the single animal place per year and to farm output (kg milk).

2 Materials and method

2.1 System boundaries and database

The process chain covers the water needed in the production of the building and equipment materials and begins with material supply. A cradle-to-gate approach was chosen and it ends with the newly constructed building. The accounting was done on an inventory level using cumulative Life Cycle Inventory (LCI) results (water resources from nature) from Ecoinvent database V2.2 (2010).

Ecoinvent database distinguishes water by source (lake, river, salt/ocean, salt/sole, unspecified natural origin, well in ground) and use (cooling, turbine use). Data are given without distinguishing between consumptive and non-consumptive water use and not considering degradation and environmental impact. Of the water needed for the production of goods, a fraction is consumptive and the non-consumptive share may be reusable or not according to the degree of degradation (Pereira, 2005). In this investigation, only the consumptive water was accounted for. This is defined as water which is ultimately withdrawn from a watershed. It includes interbasin-transfer to other catchment areas, evaporation (dissipative use), and incorporation into products (Koehler, 2008; Owens, 2002). Consumptive water use can be in-stream or off-stream. Off-stream water consumption refers to water which is removed from its natural body, e.g., incorporated in agricultural products, evapotranspiration of irrigation water in agriculture, unused irrigation water discharged in a different watershed, or use of tap water for industrial or agricultural processes (Owens, 2002; Bayart et al., 2010). In-stream water consumption refers to the in situ use of water, e.g., additional evaporation due to hydropower generation or transport of goods, or evaporation during in-stream electricity production, water from rivers.

Following de Boer et al. (2012) in using Ecoinvent data, it was assumed that 95% of the cooling water returns to the original water body, while the remaining 5% are consumptive water. Salt water was excluded as its availability is unlimited. Turbine water was excluded as its use is not consumptive. Water from lake, river, well or unspecified sources was considered to be 100% consumptive and was used in the calculation. The calculated consumptive water demand of the building materials is shown in Table 1.

Table 1 Water needed for the production of materials (calculated based on Ecoinvent 2010)

Material	Consumptive water use/L kg^{-1}
Concrete, normal B35/25	1.55
Concrete B45/35	1.51
Poor concrete	2.33
Aerated concrete	1.97
Mastic asphalt	1.73
Light-clay brick	0.34
Sand-lime brick	1.86
Lime mortar	65.70
Cement mortar	1.94
Fiber cement corrugated slab	8.26
Polyvinylchloride (PVC)	31.31
Polyethylene terephthalate (PET)	17.55
Polyethylene terephthalate, nonwoven	44.32
Polyethylene (PE)	4.72
Polypropylene (PP)	6.61
Polyethylene, LDPE	4.99
Rubber, synthetic	18.74
Glass fiber reinforced plastic, Polyamide	142.35
Rock wool	10.97
Sand	1.49
Wood	1.30
Reinforcing steel	17.69
Stainless steel	66.31

For each building type and equipment, the materials were determined and their masses were assessed (Table 2). The mass of each material was multiplied by the water consumed per kg material in production. The amount of water per barn was subsequently divided under consideration of service life (years)) and animal places in the barn. The service life of the buildings was assumed to be 25 years, the service life of technical equipment 12 years, and that of rubber mats 8 years.

For storage facilities, the amount of water per building was related to service life (years) and storage volume (m^3). The result is the volume of indirect water demand per animal place and year for barns and equipment, and the volume of indirect water demand per m^3 storage space and year for storage facilities.

Table 2 Mass of the building material groups in different variants of animal houses with slatted floor (Calculated based on Kraatz, 2008)

Material	Closed cold Barn /kg	Light construction barn/kg	Outdoor climate barn/kg	Closed insulated barn/kg	Young cattle house /kg	Calf house /kg
Reinforced Concrete (B25+B45)[1]	1,501,825	1,501,825	1,501,825	1,514,036	884,670	105,988
Concrete and light concrete	2,159,487	2,159,487	2,159 487	2,276,213	475,502	8,190
mastic asphalt	9,885	9,885	9,885	9,885	0	637
Sand lime brick	72,744	72,744	72,744	72,744	0	19,707
Lime mortar	9,301	9,301	9,301	9,301	0	1,280
Wood	135,776	120,134	128,722	120,134	119,579	20,338
Brick wall	41,537	41,537	41,537	41,537	41,537	6,160
Polymers[2]	450	1,849	514	450	400	82
Sand	48	48	48	48	0	1
Fiber cement Corrugated slab	59,103	0	59,103	78,502	28,282	5,100
Mineral wool	0	0	0	9,698	0	0
Steel	0	6,800	914	0	0	0

Note: 1. the numbers refer to the strength grade of concrete; 2. polyvinylchloride, polyethylene.

2.2 Livestock operation

Investigations were performed for a livestock husbandry system along the lines of the defined standard procedure according to Kraatz (2012) with 180 dairy cows. The following assumptions were made: the calving performance is 1.0 per year, calving is continuous, about 50% of the calves are female, and all male calves are sold after two weeks. The replacement rate is 44%, the age at first calving is 25 months. Different livestock buildings are used for calves, young cattle and dairy cows. The accommodation of calves and young cattle is divided into three age classes each. All livestock buildings are considered to be new. For feeding, a total mixed diet with the input of pasture in the summer is assumed. Dairy cows are assumed to produce 8000 L milk yr^{-1}.

We analyzed four types of livestock buildings for dairy cows, a calf barn and a young cattle barn. Two floor variants were calculated for each building type (with and without slatted floor). Furthermore, storage buildings for liquid and solid manure and two silo types in three material variants were analyzed. The standardized building types are defined by Kraatz (2012).

New buildings are considered for all livestock houses. The barns for dairy cows are assumed to have 180 animal places. Calculations were made for four variations of building shell. Furthermore, each barn type is calculated both with slatted floor and without slatted floor.

I. closed, cold/thermal non-insulated animal house

This barn type is common for newer cattle houses in Germany. Pillars and walls are made of wood and the roofing is made of fiber-cement panels with a light-band ridging.

II. outdoor climate house

This barn type is becoming more and more common in Germany. One gable is open with a wind protection net; the other walls are made of wooden space boards. The roof is similar to variant I.

III. closed, warm/thermal insulated animal house

This massive construction is common in Germany, especially for older buildings. The exterior walls are made of concrete, and pillars are made of reinforced concrete. The roof is covered by fiber-cement panels. There is also an intermediate ceiling between roof and floor consisting of fiber-cement panels and thermal insulation.

IV. light construction

This barn type consists of a steel space structure covered by canvas, and with wooden sidewalls.

The calf house and the young cattle house are closed, cold, thermally non-insulated animal houses like variant I. The pillars and walls are made of wood and the roofing is made of fiber-cement plates with light-band ridging. The calf house has 43 animal places; the young cattle house has 132 animal places.

Storage facilities comprise buildings for excrement storage and forage storage. Slurry is stored in elevated/

above-ground tanks with a capacity of 975 m³. There are three material variants: concrete, steel, and reinforced concrete. They are subdivided into open and covered types (concrete variant: concrete cover, steel and reinforced concrete variants: plastic tent cover). Liquid manure is stored in above ground concrete tanks with a capacity of 845 m³ in accordance with the standard procedure.

A concrete slab (concrete and reinforced concrete variants) is used for storing solid manure. In order to obtain a higher stack of solid manure, one variant has concrete walls on three sides of the concrete floor. The storage capacity is 1,500 m³.

Forage facilities are divided into facilities for roughage and for concentrate. Bunker silos are typical for storing basal feed. They are made of steel or polyamide and have a concrete floor. Their standard capacity is 1680 m³. The material is concrete or reinforced concrete. Tower silos made of concrete, steel or glass fiber reinforced plastic (polyamide) are typical for storing concentrate. The storage capacity in this calculation is 921 m³. Storage facilities made of steel and glass fiber reinforced plastic with 60 m³ storage capacity are also used for concentrate storage.

The technical equipment in the barns includes a manger built of reinforced concrete, a trough (concrete with polymer coating), partition grids and accessories, self-locking yoke and accessories, feeding rack and accessories, cubicle division and accessories, hay bunk (metal), cattle brush and compensatory brush, slurry pipe, rubber mats (polymers), heating system, tiltable drinking through (all stainless steel), drinking trough (stainless steel) and accessories (metal).

2.3 Calculation

The amounts of water needed for the production of all materials occurring in the livestock houses, storage facilities, and technical equipment are listed in Table 1. The masses of the building material groups in different variants of animal houses are listed in Table 2.

3 Results and discussion

The demand for indirect water ranges from 1.4 m³ animal place^{-1} yr^{-1} (without slatted floor) to 1.8 m³ animal place^{-1} yr^{-1} (with slatted floor) for light construction barns, outdoor climate barns and cold insulated barns. Only the thermally insulated barn displays a demand of 0.1 m³ higher for each floor variant (Table 3).

Table 3 Indirect water demand for livestock houses

Barn type	Indirect water demand							
	Without slatted floor				With slatted floor			
	Per barn /m³	Per animal place /m³	Per animal place and year/m³	Per kg milk /L	Per barn /m³	Per animal place /m³	Per animal place and year/m³	Per kg milk /L
Closed, cold/ thermally non-insulated	6377.5	35.4	1.4	0.2	8201.3	45.5	1.8	0.2
Light construction	6330.3	35.2	1.4	0.2	8154.2	45.3	1.8	0.2
Outdoor climate	6430.5	35.7	1.4	0.2	8254.4	45.9	1.8	0.2
Closed, warm/Thermally insulated	6904.2	38.4	1.5	0.2	8728.1	48.5	1.9	0.2
Young cattle house	1744.5	13.2	0.5	-	2763.0	20.9	0.8	-
Calf house	343.1	8.0	0.3	-	428.6	10.0	0.4	-

For calf houses, indirect water demand ranges from 0.3 m³ animal place^{-1} yr^{-1} to 0.4 m³ animal place^{-1} yr^{-1}. For young cattle houses it is 0.5 m³ animal place^{-1} yr^{-1} to 0.8 m³ animal place^{-1} yr^{-1}. The indirect water demand for technical equipment ranges from 0.2 m³ animal place^{-1} yr^{-1} (calves) to 0.7 m³ animal place^{-1} yr^{-1} (dairy cows, Table 4). The indirect water demand for feed storage ranges from 0.01 m³ m^{-3} yr^{-1} (bunker silo, concrete) to 0.5 m³ m^{-3} yr^{-1} (concentrate storage, steel) (Table 5). For excrement storage, it ranges from 0.01 m³ m^{-3} yr^{-1} (slurry storage, concrete) to 0.08 m^3 m^{-3} yr^{-1} (slurry storage, steel) (Table 6). For storage buildings made of one or two materials, a correlation between material and indirect water demand can be seen. Steel and metal materials result in a higher indirect water demand than concrete.

The indirect water demand for barn and technical equipment together accounts for 2.5 m³ animal place^{-1} yr^{-1}. Related to a dairy cow which produces 8,000 kg fat and protein-corrected milk (FPCM) yr^{-1}, this will result in 0.3 L kg^{-1} FPCM.

A direct comparison with values obtained by other authors is not possible, since indirect water use for farm buildings has not been investigated before. In relation to the total water use for milk production, the indirect water demand is low (Table 7). Depending on the methodology applied in the estimation, the water used to produce 1 kg milk ranges from 14 L to 5,000 L (Ridoutt et al., 2010; Chapagain and Hoekstra, 2003; Mekonnen and Hoekstra, 2010; de Boer et al., 2012; Prochnow et al. 2012; Haileslassie et al., 2011). Hence, the percentage of indirect water accounts for 0.02% to 2.10% and is negligible. This is in agreement with experiences from calculating the energy intensity in dairy farming (Kraatz, 2012).

The indirect water required for purchased fertilizer, diesel, electricity and gas was found to be negligible as well (i.e. total%) (de Boer et al., 2012). Although the demand for indirect water for machines is still unknown, it can be expected that the total indirect water requirement is low in relation to the overall demand for water in milk production.

Table 4 Indirect water demand for technical equipment

	Indirect water demand			
	Technical equipment in barn/m³	Technical equipment per animal place/m³	Technical equipment per animal place and year/m³	Technical equipment per kg Milk/L
Dairy Cows	1402.5	7.8	0.7	0.1
Young Cattle	1002.6	7.6	0.6	-
Calves	79.2	1.8	0.2	-

Table 5 Indirect water demand for feed storage (Silo)

	Material	Indirect water demand			
		Storage capacity/m³	IW in storage facility/m³	IW per m³ storage room/m³	IW per m³ storage room and year/m³
Bunker Silo	Concrete	7056	1605	0.23	0.01
	Concrete	1680	594	0.35	0.01
	Reinforced concrete	1680	705	0.42	0.02
Tower Silo	Concrete	921	449	0.49	0.02
	Steel	921	4314	4.68	0.19
	Glass fiber reinforced plastic	921	1851	2.01	0.08
Concentrate storage	Steel	60	753	12.55	0.5
	Glass fiber reinforced plastic	60	319	5.32	0.21

Table 6 Indirect water demand for excrement storage

		Indirect water demand		
		In storage facility/m³	Per m³ storage room/m³	per m³ storage room and year/m³
Slurry storage, Concrete	without cover	352	0.36	0.01
	with cover	487	0.5	0.02
Slurry storage, reinforced concrete	without cover	492	0.5	0.02
	with cover	512	0.52	0.02
Slurry storage, steel	without cover	2011	2.06	0.08
	with cover	2031	2.08	0.08
Liquid manure storage, reinforced concrete	without cover	310	0.37	0.01
	with cover	428	0.51	0.02
Solid manure Storage concrete	without walls	560	0.37	0.01
	with walls	680	0.45	0.02
Solid manure storage, reinforced concrete	without walls	543	0.36	0.01
	with walls	663	0.44	0.02

Table 7 Total water demand in milk production and share of indirect water for farm buildings

Reference	Approach	Water flows included	Milk specification	Total water demand /L kg^{-1} milk	Share of indirect water for farm buildings in total water demand/%
de Boer et al.(2012)	LCA	consumptive use of in-stream and off-stream water	fat-and-protein corrected milk	66	0.45
Ridoutt et al. (2010)	LCA	consumptive freshwater use	total milk solids in whole milk	14	2.1
Chapagain and Hoekstra (2003)	virtual water	virtual water of feed, drinking and servicing	milk not concentrated, unsweetened exceed. 1% not exceed. 6% fat	820	0.04
Mekonnen and Hoekstra (2010)	virtual water	evapotranspiration of precipitation (green water), evapotranspiration of water extracted from surface and groundwater (blue water), dilution water to compensate for pollution (grey water)	milk, cream fat content 1-6%	1247	0.02
Mekonnen and Hoekstra (2010)	virtual water, blue water	evapotranspiration of water extracted from surface and groundwater	milk, cream fat content 1-6%	101	0.3
Prochnow et al. (2012)	farm water productivity (inverse)	transpiration from precipitation, irrigation water, tap water	fat corrected milk	758	0.04
Haileslassie et al. (2011)	livestock water productivity (inverse)	evapotranspiration in the process of feed production	milk	1111-5000	0.006-0.03

4 Conclusion

The indirect water demand for dairy farm buildings is low. With the obtained 0.3 L kg^{-1} milk, it is negligible in relation to the total water demand in milk production of 14 to 5000 L kg^{-1} milk reported in literature. Since the results are nearly equal for different building types, the indirect water demand cannot be reduced by the choice of construction. The result obtained is useful to complete a holistic view on water use in dairy production. It is recommended to decide about the integration of indirect water demand of farm buildings into water use estimations depending on the scale and the chosen methodology.

Acknowledgements

The authors gratefully acknowledge financial support by the Senate Competition Committee (SAW) within the Joint Initiative for Research and Innovation of the Leibniz Association.

References

Bayart, J. B., C. Bulle, L. Deschênes, M. Margni, S. Pfister, S., F. Vince, and A. Koehler. 2010. A framework for assessing off-stream freshwater use in LCA. *The International Journal of Life Cycle Assessment,* 15(5): 439-453.

Blackhurst, M., C. Hendrickson,and J. Sels I Vidal. 2010. Direct and indirect water withdrawals for U.S. industrial sectors. *Environmental Science & Technology*, 44 (6): 2126-2130.

Berger, M. and M. Finkbeiner. 2010. Water footprinting: How to address water use in Life Cycle Assessment? *Sustainability,* 2 (4): 919-944.

Chapagain, A.K., and A.Y. Hoekstra. 2003. Virtual water flows between nations in relation to trade in livestock and livestock products. *Value of Water Research Report Series No. 13* UNESCO-IHE. Institute for Water Education, Delft, The Netherlands

De Boer, I., I. Hoving, T. Vellinga, G. Van de Ven, P. Leffelaer, and P. Gerber. 2012. Assessing environmental impacts associated with freshwater consumption along the life cycle of animal products: the case of Dutch milk production in Noord-Brabant. *The International Journal of Life Cycle Assessment,* 18 (1): 93-203.

Descheemaeker, K., T. Amede, and A. Haileslassie. 2010. Improving water productivity in mixed crop-livestock farming systems of sub-Saharan Africa. *Agricultural Water Management,* 97(5): 579-586.

Ecoinvent V2.2. 2010 http://www.ecoinvent.org/ (accessed November 21, 2012)

Haileslassie, A., D. Peden, S. Gebreselassie, and T. Amede. 2009.

Livestock water productivity in mixed crop-livestock farming systems of the Blue Nile basin: Assessing variability and prospects for improvement. *Agricultural Systems*, 102(1-3): 33-40.

Haileslassie, A., M. Blümmel, F. Clement, K. Descheemaker, T. Amede, A. Samireddypalle, S. Acharya, A. Venkata Radha, A., S. Ishaq, M. Samad, M.V.R. Murty, and M.A. Khan. 2011. Assessment of the livestock-feed and water nexus across a mixed crop-livestock system's intensification gradient: an example from the Indo-Ganga basin. *Experimental Agriculture,* 47(S1): 113-132. Cambridge University Press

Hoekstra, A.Y., and P. Q. Hung. 2005. Globalization of water resources: international virtual water flows in relation to crop trade. *Global Environmental Change,* 15(1): 45-56.

ISO 14040 (2006) Environmental Management – Life Cycle Assessment – Principles and Framework

Koehler, A. 2008. Water use in LCA: managing the planet's freshwater resources. *The International Journal of Life Cycle Assessment,* 13(6): 451-455.

Kraatz, S. 2008. Ermittlung der Energieeffizienz in der Tierhaltung am Beispiel der Milchviehhaltung. (Determination of energy efficiency in livestock operations exemplary for dairy farming), Dissertation, Humboldt University, Berlin.

Kraatz, S. 2012. Energy intensity in livestock operations - modeling of dairy farming systems in Germany. *Agricultural Systems,* 110: 90-106.

Mekonnen, M. M., and A.Y. Hoekstra. 2010. The green, blue and grey water footprint of farm animals and animal products. *Value of Water Research Report Series* No.48, UNESCO-IHE. Institute for Water Education, Delft, The Netherlands

Milá i Canals, L., L. Chenoweth, A. Chapagain, S. Orr, A. Anton, and R. Clift. 2009. Assessing freshwater use impacts in LCA: Part I-inventory modeling and characterization factors for the main impact pathways. *The International Journal of Live Cycle Assessment,* 14: 28-42.

Milá i Canals, L., A. Chapagain, S. Orr, L. Chenoweth, A. Anton, and R. Clift. 2010. Assessing freshwater use impacts in LCA, part II: case study of broccoli production in the UK and Spain. *The International Journal of Life Cycle Assessment,* 15: 598-607.

Owens, J.W. 2002. Water Resources in Life-Cycle Impact Assessment. *Journal of Industrial Ecology,* 5(2): 37-54.

Pereira, L. S. 2005. Water and agriculture: facing water scarcity and environmental challenges. Agricultural Engineering International: *The CIGR Journal of Scientific Research and Development,* 7

Pfister, S., A. Koehler, and S. Hellweg. 2009. Assessing the environmental impacts of freshwater consumption in LCA. *Environmental Science & Technology*, 43(11): 4098-4104.

Prochnow, A., K. Drastig, H. Klauss, and W. Berg. 2012. Water use indicators at farm scale: Methodology and case study. *Food and Energy Security,* 1 (1): 29-46.

Ridoutt, B.G., S. R. O. Williams, S. Baud, S. Fraval, and N. Marks. 2010. The water footprint of dairy products: case study involving skim milk powder. *Journal of Dairy Science*, 93 (11): 5114–5117.

Wiedmann, T., J. Minx. 2008. A definition of 'Carbon Footprint'. In Pertsova, C. (Ed.) Ecological Economics Research Trends, (Chapter 1). pp. 1-11, Nova Science Publishers, Hauppauge NY, USA.