Implementing water footprints into LCA of agricultural products - review of methods

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Abstract. Freshwater scarcity is now recognized to become one of the main environmental issues in the future. However, the consideration of fresh water consumption in life cycle modeling is still in its infancy and so far, no standardized method has evolved. This work summarizes main findings of a literature review on methods to assess fresh water use in LCA of agricultural products. It provides LCA practitioners guidance in choosing an approach for conducting such studies given the current state-of-the-art. Finally it outlines needs for further development in the methods currently available.

1 Introduction

Water fulfils several essential functions for human populations: as drinking water, in food production, for hygiene and sanitation. Just as important is the function of water resources to maintain ecosystems and biodiversity, on which humans also depend eventually. Nevertheless, it is a resource under severe pressure, caused by human activities of all kind. A complex of demographic, economic and social processes leads to stress on fresh water resources, and such processes are in interdependence with a range of factors such as climate change or technological innovation [1]. Water stress can now be considered as one of the major environmental challenges of the future [1,2].

This said, it becomes clear that a responsible use of freshwater resources on this planet is of utmost importance. Assessing water use over complete production chains certainly will be an integral part of sustainable water resource management. However, approaches to do so are comparatively young. The first concept of holistic water accounting was the water footprint of Hoekstra [3]. It evolved as rather independent concept comparable to the ecological footprint and is not directly related to life cycle assessment (LCA) methods. It is only now that the LCA community starts to extensively investigate methodologies on how to

implement fresh water use into LCA, with the first reviewed articles only published lately [4-7]. The UNEP/SETAC life cycle initiative is currently working on a set of recommended methods of implementing water footprints into LCA [4] and also the ISO started to develop an international standard to assess water use in LCA. Nevertheless this means that so far no such standard exists, despite the raised interest among clients an practitioners of LCA in such a standard.
The environmental assessment of fresh water use of agricultural products is of special interest, as 70% of the world wide fresh water consumption can be attributed to agriculture [1]. That indicates the strong influence of water use on food production as well as the relevance of this sector for water resource management. Although water use is sometimes assessed in the inventory phase of LCA of agricultural products, its environmental impact is usually not. This work summarizes main findings of a literature review on methods to assess fresh water use in LCA of agricultural products. It provides LCA practitioners guidance in choosing an approach for conducting such studies given the current state-of-the-art. Finally it outlines needs for further development in the methods currently available.

2 Review of methods

The following section summarizes the main findings of an literature review on approaches of water accounting and water accounting in LCA with a focus on approaches suitable to assess water consumption of agricultural products. It lays beyond the scope of this work to summarize all investigated methods. Berger & Finkbeiner [7] provide a general review on water footprinting methods. Thylmann [8] provides a literature review (including summaries) with focus on methods to account for fresh water use in LCA of agricultural products on which this section is based. For details and specifications of the mentioned methods please refer to the mentioned publications or to the published method itself. The methods were compared under different aspects related to the comprehensiveness of the methods, their coverage of regional variation, data availability and complexity. A special focus was on whether the methods considered changes in water quality, provided characterization factors and allowed for regional specification. The main findings of the comparison are summarized in the following.
GaBi4 [9] and *Ecoinvent* [10] are LCA software tools combined with elaborate databases that are especially designed for LCA. They comprise data on water flows (differentiation of water sources possible), though sometimes afficted with uncertainty. Depending on the dataset available the data is regionally specified.

Water input quality is not considered; water output quality is covered to a certain extent by covering environmentally relevant outputs like toxic substances or substances with eutrophication potential. So far all software does not include integrated impact assessment for freshwater use.

Hoekstra et al. [11] provide an comprehensive method on water footprinting. Specifications on how to assess water consumption of agricultural products using the FAO CROPWAT model [12] are especially valuable in case no other data sources are available. The approach using the FAO CROPWAT model can be used with high regional specification if the necessary parameter to enter in the model are available. The issue of water quality is addressed by the method of critical volumina. However, this approach does not consider water input quality, and the concept can be criticized for mixing up physical water consumption and virtual consumption calculated by using politically determined thresholds. Although a method is outlined (that considers regional differences in water availability), conducting an impact assessment according to Hoekstra et al. will be difficult due to restrictions in data availability. Direct linkage to LCA is not intended, thus no characterization factors and no linkage to areas of protection (i.e. endpoint) is made.

Pfister et al. [5] provide a comprehensive method to integrate water use into LCA. For agricultural products the approach of Hoesktra et al. [11] to use the CROPWAT model is adopted. Water quality is not explicitly differentiated, but an approach outlined how this could be done. Inventory data is not provided. Especially valuable is their approach on impact assessment that includes sophisticated consideration of regional variations in water availability, characterization factors and linkage to areas of protection. All necessary data is provided in a GIS based database on 0.5° grid cell solution.

Frischknecht et al. [13] provide a method for compiling inventories, but the suggested approach is rather coarse, as neither different water types, sources nor qualities are differentiated. Inventory data is not provided. Impact assessment is the main feature of the method. Water availability is considered in six scarcity classes, characterization factors are provided and a linkage to areas of protection is made.

Mila I Canals et al. [6] refer to Hoekstra et al. [11] for inventories, no additional specifications or data are provided. For impact assessment they consider regional water availability outlined similar to Hoekstra et al [11]. Data and characterization factors are only provided for a linkage to ecosystem quality.

Motoshita [14]: Inventories are not within the scope of the study. In their suggestions for impact assessment only human health is considered; characterization factors on national level are provided in supplemental material.

Bayart et al. [4] have outlined a complete framework to assess fresh water use in LCA. Their study is certainly of great relevance for the further development of water footprints within LCA. However, for data or characterization factors that are ready to use they only refer to existing approaches described above.

3 Discussion and suggested approach

With the methods on hand, it is now possible to account for fresh water consumption in LCA including impact assessment. However, there is no single method that covers all necessary aspects to account for fresh water consumption in LCA.

The inventory phase is best based on primary data (if available), which can be processed and supplemented by using LCA software. LCA software such as GaBi 4 [9] allows all necessary data processing and provides data on background processes (though not without uncertainty with regard to water consumption). It is very widely used to conduct LCA studies. Thus, the use of LCA software is recommended to calculate inventory data and to assess fresh water consumption in agricultural production if primary data is at hand. Hoekstra et al. [11] have provided an easy applicable approach on inventories for agricultural products that is already widely used and communicated in public. Their recommendations for the use of the FAO CROPWAT model are useful where no data on irrigation is available.

For impact assessment Pfister et al. [5] and the approach of Frischknecht et al. [13] are the only ones allowing a complete impact assessment, because they provide a method and the necessary data to use it. The approach of Frischknecht et al. provides only rough characterization factors and implies weighting according to political targets. Pfister et al. on the other hand provide comprehensive data ready to use via GIS systems. The data is provided on a spatially highly detailed level; the approach of using characterization factors is common LCA practice and straightforward to apply. The resulting impact categories are well comparable and implementable to existing LCA studies. Thus the approach of Pfister et al. can be recommended as main approach for conducting an impact assessment of fresh water use in practical applications.

4 Conclusion and outlook

The consideration of fresh water consumption in life cycle modeling is still in its infancy and so far, no standardized method has evolved. The need for a standard is clearly seen in the LCA community and in the recent past, several different methods have been published aiming to create such a standard. However, only few of them are advanced enough to be ready to use.

On inventory level practitioners have a wide choice of methods. In compliance with LCA practice, verified primary data is preferable to use. It is very likely that comprehensive water use data will soon find their way into LCA databases that will then simplify the compilation of inventories just as they do for all other material flows. Modeling water consumption with CROPWAT can be recommended if no other reliable data sources are available.

Especially life cycle impact assessment of fresh water use proves to be challenging. The method of Pfister et al. [5] is the most suitable method so far that allows a comprehensive impact assessment of freshwater use to be integrated in the common LCA approach. LCA practitioners who aim to include the environmental effects of fresh water in LCA studies are now provided with a tool to do so (a case study that uses the GaBi software and the approach of Pfister et al. to integrate water consumption into a LCA of cotton is given in Thylmann [8]). However, major revisions in methods are to be expected and current studies that integrate water footprinting into LCA are to be seen as first exploratory steps rather than fully developed approaches that deliver definite results.

Large challenges lay ahead for implementing water footprints into LCA. Further advancements are needed in the development of a harmonized, standardized and applicable method. Especially the consideration of changes in water quality is the next issue to tackle. The implementation of such methods in current LC-modeling software, including impact assessments, will be highly appreciated by the LCA community. Additionally, large improvements in the availability of inventory data needed to create water footprints are required. Another aspect that needs further consideration is temporal variability – values available so far are annual averages and in some cases it could be necessary to calculate seasonal characterization factors. Finally, LCA is not meant to be a self contained art. Not until companies, policy makers, civil society and private people understand the necessity of a responsible use of fresh water resources will the final goal of water footprinting be reached.

5 References

[1] World Water Assessment Programme (WWAP), *The United Nations World Water Development Report 3: Water in a Changing World*, UNESCO, Paris and Earthscan, 2009

[2] Koehler, A.,Water use in LCA: managing the planet's freshwater Resources, *Int J LCA* 13, 2008, 451–45

[3] Hoekstra, A.Y.; Hung, P.Q.: *Virtual Water Trade: A Quantification of Virtual Water Flows between Nations in Relation to International Crop Trade*, Value of Water Research Report Series 11; UNESCO-IHE: Delft, 2002

[4] Bayart, J.B.; Bulle, C.; Koehler, A.; Margni, M.; Pfister, S.; Vince, F.; Deschenes, L., A framework for assessing off-stream freshwater use in LCA, *Int J Life Cycle Assess* 15, 2010, 439–453

[5] Pfister, S.; Koehler, A.; Hellweg, S., Assessing the environmental impact of freshwater consumption in LCA. *Environ Sci Technol* 43, 11, 2009, 4098–4104.

[6] Milà i Canals, L.; Chenoweth, J.; Chapagain, A.; Orr,S.; Anton, A.; Clift, R, Assessing freshwater use impacts in LCA: Part I-inventory modeling and characterization factors for the main impact pathways, *Int J LCA* 14, 2009, 28–42

[7] Berger, M.; Finkbeiner, M., Water footprinting: how to address water use in life cycle assessment? *Sustainability* 2, 2010, 919–944

[8] Thylmann, D., *Implementing water footprints into LCA - methodology review and case study on cotton cultivation in the US*, Master thesis submitted at the University of Hohenheim, Germany, 2011

[9] GaBi 4: Software and Databases for Life-Cycle-Assessment and Life-Cycle-Engineering, LBP University of Stuttgart and PE INTERNATIONAL GmbH, Leinfelden – Echterdingen, 2008

[10] Frischknecht R., Jungbluth N., Rebitzer G. and Spielmann M., *Overview and Methodology. Final report ecoinvent data v2.0, No. 1.* Swiss Centre for Life Cycle Inventories, Dübendorf, Swizerland, 2007

[11] Hoekstra, A.Y.; Chapagain, A.K.; Aldaya, M.M.; Mekonnen, M.M., *Water Footprint Manual. State of the Art 2009*; Water footprint Network, 2009

[12] FAO, *CROPWAT 8.0 model*, Food and Agriculture Organization, 2009

[13] Frischknecht R.; Steiner R.; Jungbluth N., *The Ecological Scarcity Method – Eco-Factors 2006. A method for impact assessment in LCA*, Environmental studies no. 0906. Federal Office for the Environment, Bern, 2009

[14] Motoshita, M.; Itsubo, N.; Inaba, A., Development of impact factors on damage to health by infectious diseases caused by domestic water scarcity, *Int J Life Cycle Assess*, 16,1, 2011