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WATER USE IN LCA

A new water footprint calculation method integrating consumptive and degradative water use into a single stand-alone weighted indicator

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Abstract
Purpose A complete assessment of water use in life cycle assessment (LCA) involves modelling both consumptive and degradative water use. Due to the range of environmental mechanisms involved, the results are typically reported as a profile of impact category indicator results. However, there is also demand for a single score stand-alone water footprint, analogous to the carbon footprint. To facilitate single score reporting, the critical dilution volume approach has been used to express a degradative emission in terms of a theoretical water volume, sometimes referred to as grey water. This approach has not received widespread acceptance and a new approach is proposed which takes advantage of the complex fate and effects models normally employed in LCA.
Methods Results for both consumptive and degradative water use are expressed in the reference unit H_2Oe, enabling summation and reporting as a single stand-alone value. Consumptive water use is assessed taking into consideration the local water stress relative to the global average water stress (0.602). Concerning degradative water use, each emission is modelled separately using the ReCiPe impact assessment methodology, with results subsequently normalised, weighted and converted to the reference unit (H_2Oe) by comparison to the global average value for consumptive water use (1.86×10^{-3} ReCiPe points m^{-3}).
Results and discussion The new method, illustrated in a simplified case study, incorporates best practice in terms of life cycle impact assessment modelling for eutrophication, human and eco-toxicity, and is able to assimilate new developments relating to these and any other impact assessment models relevant to water pollution.
Conclusions The new method enables a more comprehensive and robust assessment of degradative water use in a single score stand-alone water footprint than has been possible in the past.

Keywords Environmental labelling · ReCiPe · Water scarcity · Water stress · Water use · Weighting

1 Introduction

Human production and consumption patterns place a heavy burden on many of the world's water systems (Ridoutt and Pfister 2010b). The international concern is such that a 'Water for Life' International Decade for Action (2005–2015) has been proclaimed by the United Nations (www.un.org/waterforlifedecade/background.html) and planetary environmental boundaries for water use have been proposed (Rockström et al. 2009), analogous to the boundaries proposed for global greenhouse gas emissions, in order to avoid widespread irreversible environmental change and intolerable impacts on human well-being. An important innovation in life cycle assessment (LCA) has been the development of inventory guidelines and new impact assessment methods for water

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use (Berger and Finkbeiner 2010; Bayart et al. 2010; Kounina et al. 2011). This work has been supported by a project group working under the auspices of United Nations Environment Programme and the Society of Environmental Toxicology and Chemistry (UNEP–SETAC) Life Cycle Initiative (Koehler 2008). In parallel, the International Organization for Standardization (ISO) is developing an international standard for water footprint based on LCA (ISO 14046).

Following the UNEP–SETAC framework (Bayart et al. 2010), water use occurs in two ways: consumptive water use (CWU), which relates to the removal of water from a water body, and degradative water use (DWU), which relates to emissions affecting water quality. As such, the assessment of water use in LCA inevitably involves modelling a variety of environmental mechanisms, with the results normally reported as an environmental profile consisting of two or more life cycle impact category indicator results. In the context of LCA, these category indicator results relating to water use can be presented alongside other relevant impact category results according to the goal and scope of the specific study.

That said, a problem arises in the context of water footprinting, where there is demand for a single stand-alone result, analogous to the carbon footprint. A profile of indicator results is clearly rich in detail and beneficial where the LCA practitioner is reporting within the LCA expert community or where they have an opportunity to provide detailed explanation and interpretation to the decision maker. However, a profile of indicator results is deemed inappropriate for communication to a remote and largely non-technical audience (such as the general public), in which case a single score reported using an intuitively meaningful unit is desirable. The importance of the single score approach cannot be underestimated because experience with carbon footprinting has shown that stand-alone environmental indicators based on LCA can achieve broad awareness in the community and even be a catalyst for life cycle thinking and management (Weidema et al. 2008).

The current approach to LCA-based water footprinting, which integrates CWU and DWU in a single score, makes use of the critical dilution approach to enable emissions to water to be expressed as a water volume (Ridoutt and Pfister 2010b). This approach is not unreasonable; however, it is not altogether satisfying because it does not make use of advancements in LCA relating to the fate, exposure and effects modelling of emissions (Finnveden et al. 2009). In addition, the critical dilution volume method, which has typically been applied in the context of agricultural fertiliser emissions, is problematic when assessing compounds which have no documented or acceptable concentration in the environment, in which case the critical dilution volume becomes extremely large or even infinite. Furthermore, this approach is also unable to account for different residence times of pollutants in the environment. The purpose of this paper is to present a new and improved approach to calculating a single score LCA-based water footprint. The method is deemed highly relevant considering the current popular interest in water footprints and the ISO international water footprint standard which is in development.

2 Method and data

A defining feature of the new method is the calculation of results for both CWU and DWU in the reference unit H_2Oe (equivalent; Ridoutt and Pfister 2010b), where 1 l H_2Oe represents the burden on water systems from 1 l consumptive freshwater use at the global average WSI (Water Stress Index; Pfister et al. 2009). Calculation of results in the same reference unit enables summation and reporting as a single stand-alone score. This reference unit (H_2Oe) is regarded as intuitively meaningful as ordinary people typically envision water use in terms of a volume. The principal that water use in a region of high water stress is more serious than water use in a region of low water stress is also readily grasped. The suitability of the H_2Oe reference unit has been confirmed in a wide range of case studies (Page et al. 2011; Pfister and Hellweg 2009; Ridoutt and Pfister 2010a; Ridoutt and Poulton 2010; Ridoutt et al. 2010a, b, 2012a, b). In regards to life cycle inventory modelling for water use, the UNEP-SETAC framework is followed (Bayart et al. 2010).

Concerning CWU, which is generally assessed by balancing water inputs and outputs (Pfister et al. 2012), the characterisation factor applied in each spatially differentiated instance (CWU_i, typically in the units m^3 or l) is the locally relevant WSI (WSI_i) divided by the global average WSI (WSI_{global}) (Eq. 1). Current recommended practice is to use the global WSI dataset of Pfister et al. (2009), or compatible site-specific WSI values calculated using the same formulae but using local hydrological data. Future updates and improvements in the WSI are also anticipated and should be adopted where appropriate. For the WSI of Pfister et al. (2009) the global average consumption weighted value is 0.602.

$$\text{Indicator result for CWU}(H_2Oe) = \sum_i \frac{CWU_i \times WSI_i}{WSI_{global}} \tag{1}$$

Concerning DWU, each emission is modelled separately according to the relevant environmental mechanism using recommended methods at the endpoint level (e.g., EU-JRC 2011 in the European context). Most commonly, this will include freshwater eutrophication, freshwater eco-toxicity and impacts relating to the human health area of protection. Other impacts, such as marine eutrophication, marine eco-toxicity and sedimentation, might also be considered, subject to the development of accepted endpoint impact assessment models. The individual endpoint results are calculated using the ReCiPe impact assessment methodology (Goedkoop et al. 2009), normalised with European factors, weighted using the Hierarchist cultural perspective (Goedkoop and Spriensma 2000; ISO 14044 Section 4.4.3.4), and combined into a single value (ReCiPe points, global). This single value is converted to the units H_2Oe by dividing by the global average consumption weighted value for 1 l of CWU, also reported in ReCiPe points (Eq. 2). Using the methodology and data presented in Pfister et al. (2009) and the methodological adjustment to ReCiPe (Pfister et al. 2011), the global average value for 1 l of CWU was assessed and found to be 1.86×10^{-6} ReCiPe points.

$$\text{Indicator result for DWU}(H_2Oe) = \frac{\text{RECIPE points (emissions to water for product system)}}{\text{RECIPE points (global average for 1l consumptive water use)}} \quad (2)$$

A single stand-alone water footprint result, expressed in the units H_2Oe, is calculated by adding the indicator results for CWU and DWU (Eq. 3).

$$\text{Water footprint}(H_2Oe) = \text{CWU}(H_2Oe) + \text{DWU}(H_2Oe) \quad (3)$$

To illustrate the method, a simplified case study is presented for an agricultural production system involving 1 Ml/ha (100 mm) consumptive freshwater use for irrigation (local WSI 0.35), and emissions of 4 kg P to freshwater and 2 kg atrazine (2-chloro-4-(ethylamino)-6-(isopropylamino)-*s*-triazine) per ha to soil. The crop yield is 5,000 kg/ha. Water use associated with the production, supply and application of fertiliser and herbicide is ignored in this simplified example.

3 Results and discussion

Despite much popular and academic interest in water footprinting, development and application of the concept has been impeded by the lack of a generally accepted method of integrating both CWU and DWU impacts into a single stand-alone metric. As mentioned in the Introduction, the critical dilution volumes approach is currently used to express a degradative emission in terms of a theoretical water volume, sometimes referred to as grey water (Chapagain et al. 2006). The problems with the grey water concept are many. Firstly, the term grey water has been found to be confusing as the water industry uses this term to refer to nutrient-rich sewage from households that lacks fecal or urine contamination (Kounina et al. 2011). In addition, some stakeholders have expressed the mistaken understanding that a literal dilution of chemical pollutants is being advocated. From a scientific perspective, modelling of emissions in terms of a theoretical dilution volume is crude in comparison to the complex fate and effects models otherwise employed in LCA.

The new water footprint calculation method presented in this paper represents a new way of calculating a single stand-alone water footprint metric without requiring use of the grey water concept. The new method incorporates best practice in terms of life cycle impact assessment modelling for eutrophication, human and eco-toxicity, and is able to assimilate new developments relating to these and any other impact assessment models relevant to water pollution which are compatible with ReCiPe. In regards to the latter, sedimentation may be an important impact on water for many land-based production systems (Masters et al. 2008) as well as heat emissions from power production (Verones et al. 2010).

To avoid possible misunderstanding, it is stressed that the water footprint metric presented in this paper is not intended for use in an LCA where it is presented alongside other relevant impact category indicator results — as this would likely result in a problem of double counting. The specific purpose of this LCA-based water footprint metric is to enable stand-alone reporting of water use impacts as a single value with highly communicable units (i.e., 1 H_2O equivalent). Such reporting is deemed appropriate for the communication of water use impacts to a general public audience as a means of raising awareness and motivating patterns of sustainable consumption and production. It might also be combined with carbon and land use footprints for the purpose of eco-labelling.

A choice that was made in developing the method was to assess CWU using a midpoint method (using WSI-based characterisation factors) rather than an endpoint method. The midpoint approach was preferred because the same calculation method used to derive the global WSI dataset can also be used to generate study specific values based on local hydrological data. For product systems where impacts from CWU are substantial, the additional effort associated with refining the WSI-based characterisation factors may be worthwhile.

For the simplified agricultural case study, the indicator result for CWU was 0.58 Ml H_2Oe ha^{-1} or 116 l H_2Oe kg^{-1} crop product (Eq. 4, based on Eq. 1). The numerical value of the indicator result is less than the CWU because the local water stress in this example is below the global average. In another situation where the local water stress was above the global average, the numerical value of the indicator result would exceed the CWU.

$$\text{Indicator result for CWU}\left(\text{Ml } H_2Oe \text{ ha}^{-1}\right) = \frac{1.0 \times 0.35}{0.602} = 0.58 \quad (4)$$

For the case study, P and atrazine emissions were assessed at 2.77 and 0.19 ReCiPe points ha^{-1}, respectively. As such, the result for DWU was 1.59 Ml H_2Oe ha^{-1} or 318 l H_2Oe kg^{-1} crop product (Eq. 5, based on Eq. 2).

$$\text{Indicator result for DWU}\left(\text{Ml H}_2\text{Oe ha}^{-1}\right) = \frac{(2.77+0.19)}{1.86} = 1.59 \quad (5)$$

Finally, combing the results for CWU and DWU into a single score, the water footprint was 2.17 Ml H_2Oe ha^{-1} or 434 l H_2Oe kg^{-1} crop product (Eq. 6, based on Eq. 3).

$$\text{Water footprint}\left(\text{Ml H}_2\text{Oe ha}^{-1}\right) = 0.58 + 1.59 = 2.17 \quad (6)$$

4 Conclusions

The new water footprint calculation method presented and demonstrated in this paper makes it possible to report a single stand-alone LCA-based result combining potential environmental impact from CWU and DWU. This new method will make possible a more comprehensive and robust inclusion of DWU in a water footprint than has been possible in the past using the grey water concept. That said, water footprint practitioners should continue to be mindful of uncertainties relating to both the inventory data and the individual impact assessment models used in ReCiPe. We hope that this new method will contribute positively to the development of the water footprint and consequently to more sustainable use of the world's water resources.

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