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EDITORIAL

Water use in LCA: managing the planet's freshwater resources

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1 Setting the scene

Freshwater is one of the planet's most valuable resources being an essential life-sustaining element which cannot be substituted. Acting as the source of drinking water and the basis for hygiene and food supply, it is indispensable for humans, while at the same time ensuring biodiversity and pivotal ecosystem functions on which ultimately we all depend. We are witnessing a steadily worsening situation of rapidly decreasing freshwater resource availability which threatens 1.1 billion people around the globe lacking sufficient access to safe drinking water (UN 2006). Spreading water scarcity in many regions of the world endangers food production (about 70% of today's global freshwater consumption feeds agriculture!), puts food security at risk, and burdens human health due to malnutrition (e.g., in Asia and Africa). The overexploitation of surface water bodies and (fossil) groundwater for the soaring agricultural production (e.g., in China, India, Western USA) may jeopardize the freshwater abundance of future generations. Irrigation and damming cause fragmentations of river basins drastically reduce the downstream freshwater availability and alarmingly threaten aquatic and terrestrial ecosystems. Inappropriate water resource management endangers ecological functions and biodiversity, provokes disturbed water cycling and desiccation of rivers, streams, and land.

If all that were not bad enough! On top, climate change promises to intensify the looming water crisis by changing rainfall patterns and inducing elevated evaporation and dramatic droughts in many regions of the world: Some 20% of the increase in water scarcity in the coming decades will be caused by climate change according to recent UN estimates (UN 2006). Being a fundamental building block for human civilization and economic development, freshwater also is a strategic resource, just like energy (Wall Street Journal 2008). Freshwater resources and their allocation increasingly play a central role in poverty alleviation and urban water supply, facing growing competition with other economic sectors particularly in low and middle income countries. Rapidly rising urban populations mount the pressure to shift water from agriculture to vastly expanding cities (e.g., in China). Global trade of manufactured goods and services, all of which require water at some point, fuel the demand for capturing the freshwater use-related environmental, economic, and social impacts (for definition of *freshwater use*, see Section 2).

This is where life cycle-based sustainability assessment concepts come into play. Particularly, life cycle assessment

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(LCA), with its focus on the *environmental* consequences of global value chains and the potential to concurrently capture geographically specific impacts, moves into the spotlight of methods being capable to provide decision support related to environmental performance of human freshwater use, be it domestic, industrial, or agricultural. Just like for the carbon footprint (Pant et al. 2008), LCA offers the framework to deliver meaningful information on the 'water footprint' of manufactured goods, delivered services, business operations, and of consumers' behavior, while always keeping the eye open for other relevant areas of environmental concern in order to avoid problem shifting across environmental problems and life cycle stages (ISO 14040 2006).

Despite these rather obvious capabilities of LCA, the topic of freshwater use has traditionally received very limited attention in LCA. The development of the methodological basis is still in its infancy and one may speculate about the reasons: The LCA methodology was essentially shaped by method developers in industrialized countries practically not (yet) suffering from water scarcity. A fact which provides a straightforward but rather plausible explanation! Reflecting the world's water woes, locally, regionally, and globally, there is, however, an urgent need for methodological solutions to properly account for freshwater-use related environmental impacts of a product's life cycle and globalized value chains, many of which exhibit unsustainable use of freshwater resources.

2 State of the art

2.1 Resource classification

Freshwater is the only abiotic natural resource which is renewable and finite at the same time. This is generally acknowledged, but one may also argue that freshwater, similar to topsoil (Lindeijer et al. 2002), represents a mix of abiotic and biotic components consisting of the life-sustaining element water, minerals, and a immeasurable variety of biological life (e.g., phytoplankton forming the ultimate base of most freshwater food webs). Unlike minerals and fossil energy carriers, which are mostly concealed outside the biosphere, freshwater is strongly interconnected with the biosphere. Its drastic decline caused by human activities has direct influence on ecosystems and in extremely water-scarce areas most likely also on human health. Following the standard classification for abiotic resources in LCA (e.g., Finnveden 1996; Guinée 2002; Lindeijer et al. 2002), three main types of freshwater resources can be identified which differ in respect to their intrinsic regeneration potential: deposits, funds, and flows. Freshwater deposits are represented exclusively by fossil groundwater stocks that are only very slightly or not replenished within human lifetimes and are therefore exhausted when tapped. Freshwater funds, such as groundwater aquifers and lakes, decline temporarily when being extracted. As long as they are not irreversibly impaired, their natural renewability allows them to regenerate. Streams and rivers belong to the flow-type resources and are characterized by a continuous flow from which humans can redirect certain quantities. In principle, freshwater flows are nonexhaustible, but as they provide a life-supporting element to the biosphere, unsustainable withdrawals from freshwater flows may have substantial adverse effects on ecosystems. For freshwater resources, one can summarize that depletion takes place whenever the replenishment capacity is exceeded by extensive withdrawals, or freshwater flows are cut down by a reduced regeneration rate having implications for the future resource availability (see also Bauer and Zapp 2004).

2.2 Life cycle inventory modeling

When coupled with information on the basic water source (e.g., river, aquifer), the aforementioned differentiation of freshwater resource types provides a basic format for structuring the water inputs and outputs in the life cycle inventory analysis. However, for the time being, a clearly defined terminology and categorization for freshwater use does not exist and, therefore, consistent and generally accepted metrics for water-related inventory parameters are missing. This is also the case for water-flow reporting in site-oriented environmental management in industry and agricultural production. A trend-setting distinction for water quantity indicators and use types was provided by Owens (2002) who separated in-stream (e.g., hydroelectric generation) and off-stream (after withdrawal) water use and classified indicators for 'use'[1] and consumption. Building on this former work, the author of this editorial defines *freshwater use* to embrace both *utilization and consumption*: Freshwater utilization represents the water quantity used associated with water flows which are returned to the original river basin, while consumption characterizes the ultimate withdrawal from a watershed including inter-basin transfer to other catchment areas, evaporation (dissipative use), and incorporation into products. For any type of use, quality degradation can take place.

If at all, most LCA studies and databases that report water elementary flows simply stick to the total input of water used, some determine the water source (e.g., ecoinvent database) while neglecting the water outputs

[1] The term 'use' as defined by Owens (2002) equals 'utilization' in the definition provided by the author of this editorial.

from the LCA system. Also, no LCA database available consistently reports water inputs and outputs for *every* dataset included. In contrast, Rebitzer et al. (2007) proposed a scheme that additionally considers water output categories providing a first concept for meaningful inventory water balances, for both foreground and background processes. As the simplistic measure of total water volume supplies only insufficient information for an adequate assessment of freshwater use, the distinction between inventory input and output water flows seems to be as essential as balancing biogenic carbon dioxide in terms of uptakes and emissions. The strict differentiation between freshwater *utilization and consumption* in the inventory is equally important because it allows accounting for the dissipative losses indicating the extent to which downstream users, both humans and ecosystems, might be deprived of freshwater.

2.3 Life cycle impact assessment

In the assessment from a product life cycle perspective, water quantity issues are strongly interrelated with water quality aspects. Quality specifications of water flows indicate the adequacy as input for a particular application and the potential for reuse of discharged water outputs, an option which mitigates the necessity to withdraw freshwater from nature (e.g., use of reclaimed water for agricultural irrigation). Water quality impairments in terms of chemical impurities are already broadly covered by current LCA methods (e.g., CML 2001; Eco-indicator 99; IMPACT 2002+; ReCiPe 2008; Koehler 2006). These quantify the environmental burdens of ecotoxic, nutrifying, and acidifying waterborne emissions. Other relevant qualitative aspects such as heat releases and microbial contaminations still remain uncharacterized, the latter one representing a major cause of human diseases in regions as Asia and Africa. Likewise, the additional reduction of freshwater availability as a consequence of deteriorated quality of freshwater reservoirs has not been addressed so far in LCA, accordingly an evaluation of impacts resulting from this cause–effect chain is neglected.

Similar to the inventory modeling of freshwater use, the development of appropriate life cycle impact assessment (LCIA) methods has not substantially advanced over the last years. Different assessment frameworks for abiotic resources exist and they partly address freshwater as a resource (e.g., Lindeijer et al. 2002; Steward and Weidema 2005; Brent 2004; ReCiPe 2008). Yet, these frameworks are not specific to freshwater. Steward and Weidema (2005), for instance, introduce the backup technology concept, a scheme that proposes to assess the impacts from today's freshwater use as the environmental consequences from future extractions of water (e.g., by desalination of saltwater), which ultimately might be applied for compensating the freshwater presently depleted by human activities. Most LCIA methods (e.g., CML 2001; Eco-indicator 99; IMPACT 2002+) have considered freshwater resources to be nondepletable and therefore are lacking characterization models for freshwater exhaustion. In contrast, operational characterization factors for freshwater consumption are given in exergy-based methods which account for the chemical and potential exergy content of freshwater (Bösch et al. 2007 (CExD); Dewulf et al. 2007 (CEENE)). Solely, the Swiss Ecological Scarcity method 2006 (Frischknecht et al. 2008) so far features spatially differentiated ecofactors for freshwater use, assigning higher relative weights to regions of elevated water stress. All these methods, however, are restricted to evaluating the impacts on the freshwater resource itself and its depletion. They refrain from providing models that quantify the impact pathways expressing the damages on human health and ecosystems and thus disregard the full range of environmental effects.

3 Current developments and future challenges

In order to overcome these methodological deficiencies, a project group was funded under the auspices of the United Nations Environment Programme/Society of Environmental Toxicology and Chemistry Life Cycle Initiative in 2007, comprising researchers from different international academic institutions and practitioners representing various industries. Their goal is to develop an integrative inventory scheme in line with a midpoint–endpoint LCIA framework for the assessment of freshwater use. Together with methods for LCI modeling, a harmonized suite of characterization models specifying the damages to the areas of protection, human health, ecosystem quality, and natural resources, and, where relevant, man-made environment (Udo de Haes et al. 2002) will be provided. Recommended practice and guidance for LCA practitioners to adequately account for freshwater resources (e.g., in data collection) shall be established (Koehler and Aoustin 2007).

While many advanced tools and analytical methods for integrated water resource management exist, scientific efforts in LCA should be directed towards methodologies that allow, at an appropriate level of detail, effort, and sophistication, for comparing product alternatives based on different production systems (e.g., irrigated versus rain-fed agriculture) and inducing multiple consumption patterns (e.g., conventional versus dual-flashed water saving toilets). LCA is most beneficial in revealing the trade-offs between freshwater use-related aspects and other multifaceted environmental problems over the entire life cycle and across different regions. Therefore, site-specific local impacts of freshwater abstraction (e.g., on local aquatic ecosystems) must be covered by environmental assessment tools other than LCA, for instance environmental impact assessment and risk assessment.

To arrive at meaningful LCA results, we, as an LCA community, must develop *operational* assessment procedures for LCI and LCIA that reflect the geographically diverse and time-variant character of freshwater resources. Here, various levels of detail for inventory modeling and impact characterization are possible, for instance with a country, river basin, and ecoregion scope. However, the level of sophistication both in LCI and LCIA should not disregard the reality of freshwater use-related information obtainable *on a product level*. To date, data availability on freshwater use proves to be a limiting factor for establishing meaningful water footprints of products. Also, the author believes that, in principle, all figures reported so far on freshwater use are inherently wrong due to the missing harmonized and broadly accepted reporting scheme (I do it this way, you do it that way!). In the future, a tight convergence of data supplied by site-oriented environmental management systems and data needs for adequate life cycle inventories must be reached. Certainly, this calls for a standardization of current reporting formats in business and industry, specifically in agriculture (e.g., for corporate ecobalances and environmental/sustainability reports), if adequate product-related information on freshwater use is to be supplied. Yet, this is feasible if reporting requirements are defined as generic and practical as possible but as concrete as necessary both in terms of water type and quality as well as spatial and temporal level of detail.

Aiming at broad application, interaction with other communities, particularly water science, hydrology, water resource planning, and ecology, is crucial to reach validity and high acceptance of freshwater use assessment methods being developed. Cross-fertilization with concepts already in place in the context of integrated water resource management, such as the virtual water concept (Allan 1998) and the water footprint metrics (Hoekstra and Chapagain 2007), may stimulate the LCA method development and provide hints for simplification. Also, available tools such as the Global Water Tool (WBCSD 2007), an online resource to calculate water consumption and efficiency across a company's facilities around the world, may foster freshwater use-related LCI development by indicating potentials and drawbacks in corporate water reporting.

Since freshwater has an economic value in all its competing uses, freshwater shortages provoked by unsustainable consumption and production may cause job losses and increases in the water price in a particular water-scarce region. Economic activities sustained by freshwater use may, at the same time, lead to increased economic wealth, which in turn enables an additional purification of water having low quality in regions suffering from water scarcity. Such manifold and grave socioeconomic consequences of freshwater use and depletion can not be covered by LCA but should in any case be dealt with in life cycle based social and cost assessments (Klöpffer 2008; Hunkeler 2006; Hunkeler et al. 2008).

Not only to the author of this editorial but rather to many LCA developers and practitioners, it has become evident that the proper integration of operational assessment methods for freshwater use into LCA will inevitable strengthen the significance of LCA analyses in product-related decision making. This is particularly true for the agricultural and water supply sectors. But also other industries, among many others the chemical, energy, pulp and paper, and aluminum industries, show a considerable interest in efficient methods to be implemented into tools for product stewardship which assist to proactively manage sustainable rationing of freshwater resources. It is, thus, essential and very timely to add a Section on 'Water Use in LCA' to the International Journal of Life Cycle Assessment.

4 Invitation for paper submissions

The scope that we foresee for this section could encompass the following principle themes, though they are doubtless to expand in response to the upcoming contributions:

– Inventory modeling of water use-related activities: classification of flows, modeling in attributional and consequential LCA studies
– Approaches for geographical differentiation discussing the potential compromises between generalization and site specificity, both within LCI and LCIA
– Methodologies for relevant impact pathways of freshwater use for the different areas of protection, with a particular focus on isolating the cause–effect chains triggered by loss in freshwater availability and loss in quality, respectively
– Development of operational characterization factors on midpoint and endpoint level, including elaborations on their borderlines and appropriateness for foreground and background systems (e.g., feasibility of aggregating different water use impacts along the life cycle, different levels of sophistication)
– Interrelations and disjunction of impacts caused by freshwater use and other environmental interventions such as land use (e.g., rainwater losses due to evapotranspiration from nonsealed agricultural land)
– Case studies, particularly on freshwater-intensive product systems and technologies, highlighting contributions of direct and indirect freshwater use in different product life cycle stages and contrasting the relative importance of freshwater resource abstraction versus other environmental consequences (trade-offs)

– Relations to other sustainability assessment methods and tools (social LCA, life cycle costing, etc.)

With this list of topics, we would like to invite method developers and practitioners to submit articles within the area of Water Use in LCA. Thus, we hope to stimulate publications and methodological advancements contributing to an improved inventory analysis and impact assessment of freshwater resources. Such complements will help us to decrease our environmental impact intensity to move another step ahead towards sustainable consumption and production.

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