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Indirect water management: how we all can participate

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Abstract Life Cycle Assessment (LCA) represents a methodological framework for analysing the total environmental impact of any product or service in our daily life. After tracking all associated emissions and the consumption of resources, this impact is expressed with respect to a few common impact categories. These are supposed to reflect major societal and environmental priorities. However, despite their central role in environmental processes, to date hydrological and hydrogeological aspects are only rarely considered in LCA. What are the reasons? The origin of LCA plays a major role; it has been mainly applied in the industrial sector. Here, if at all, water turnover and use is described, but less emphasis is paid to the related effects. This incompleteness can be also found in water footprint or virtual water based evaluations. Our approach, presented here, fills this gap, and reveals how a revised LCA and the related water footprinting can serve as a consistent baseline for indirect water management involving producers, consumers, and local stakeholders.

Key words IWRM; LCA; freshwater use; impact assessment; wheat; agriculture; virtual water

INTRODUCTION

Integrated water resources management (IWRM) stands for a systematic approach for sustainable, equitable, and efficient development of water. It promotes the coordinated implementation of multifaceted programmes that address water supply and demand, while complying with environmental requirements in a basin or a watershed (e.g. Meire *et al.*, 2008). According to the Dublin principles, IWRM should be based on a participatory approach, involving users, planners, and policy makers at all levels. Its challenges are to combine approaches and standpoints of multiple disciplines, to understand and predict the characteristics of each particular real case, and to involve the variety of associated stakeholders. In this sense it offers recipes for local or regional management plans, and thus commonly is constrained to a limited area. The principal perspective of water management is unidirectional, and originates from the case-specific problems that need to be solved. Thus, solution strategies focus on direct effects. In this fashion, the role of external pressures may be acknowledged but is taken as given and is not subjected to further discussion.

In this paper, we focus on these "external pressures" and present a concept that also enables control of the underlying factors. Naturally, the scale of such a different perspective will be coarser than usual in IWRM applications, and is only complete on a global level. As will subsequently be shown, an orientation for the smallest scale, for individuals' daily decisions, can be derived by using a holistic concept. Even if not living within one particular watershed, people can ultimately exert indirect water management. The methodology presented follows life-cycle thinking, and hence is embedded in a standard life cycle assessment (LCA) framework. In the following section, the underlying principles of LCA will be explained, and its link to established IWRM practice will be elaborated. As a side effect of embedding indirect water management in LCA, tradeoffs with other environmental concerns can be shown in a consistent manner.

LIFE CYCLE ASSESSMENT, LCA

LCA is a modular procedure to quantify and compare the environmental burdens of any product, service, or good. It is based on ISO standards (ISO 14040 series), and involves sequential procedures such as "Goal and Scope Definition", "Inventory Analysis" (LCI), "Impact Assessment" (LCIA) and "Interpretation" (e.g. Guinee *et al.*, 2002, Fig. 1). The purpose is to fully examine the environmental burdens or benefits, that is, those that stem from the entire life cycle of a product, from cradle-to-grave. For example, a bottle of wine would not only be characterized by the net water in

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the bottle, but all the water that is spent for grapevine irrigation, grape-crushing, as well as water that is consumed for glass production, bottling, transport and all the effects from recycling and disposal. LCA follows a holistic paradigm, often at the expense of accurate estimations. This fact does not necessarily mean a disadvantage, as it gives LCA the space to perform a combined investigation of multiple different safeguard subjects and assessment criteria. These are distinguished by different standard impact categories such as global warming, ozone depletion, land use, depletion of natural resources, and toxic effects. The normative values that reflect the impacts within each category are scientifically based, but often have to be understood as rough reference figures for comparative assessment. This is due to the specific assumptions for calculating indicators and their commonly approximate nature.

Compared to standard impact categories within LCA, water is special. In contrast to other abiotic resources such as coal or crude oil, it can be replenished. In contrast to CO_2 emissions, there exists an immense spatial dependency of impacts on natural water bodies. Total global freshwater resources are sufficient, but not evenly distributed and often scarce in regions of high demand. Natural resources are difficult to assess if their value is not just local (e.g. on a community or industry scale), but on a societal level (like health effects). Setting up functional relationships in order to derive a generally valid and practicable evaluation is tedious due to the complex, insufficiently understood, and uncertain natural processes involved. This is also true for those effects and processes connected to natural water systems.

LCA that includes the environmental effects of water use and consumption means global *indirect* water management. It supports goal-directed consumer behaviour that aims to reduce pressure on natural water systems. By developing a hydrologically-based assessment of potential impacts from human interaction with natural water bodies, “greener” products can be favoured. Let us consider the wine example: For different wine labels, tracking the effects of irrigation in different grape cropping regions would reveal that brand with the lowest local impacts. If consumers are not only guided by taste but also such an “ecolabelling”, they could choose products based on sustainable and environmentally friendly water management. The focus of such an assessment can be on comparisons between regions but also on absolute values (thresholds).

In the following we briefly review some studies that are dedicated to the question of how to account for hydrological and freshwater issues in common LCA concepts. Then, we concentrate on the most water consumptive sector, agriculture, and show how to compile the water-efficiency of cropping and regional water availability. As an illustrative example, global wheat farming is chosen, as wheat is one of the crops with the greatest acreage worldwide.

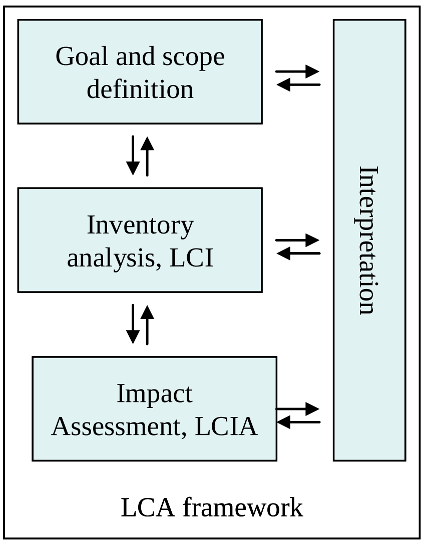

Fig. 1 LCA components (adopted from ISO 14040, 2006; ISO 14044, 2006).

RELATED WORK

Despite the complexity of accounting for the impacts in hydrological environments in a both comprehensive and expressive way, several approaches have been suggested to overcome the rudimentary state of the art. For example, Owen (2002) presented a conceptual overview of requirements for integration of water resources into LCA. This work represents a general introduction into this transdisciplinary field, and structures potential impact types related to water quantity and quality. However, it focuses on a verbal discussion and does not embody substantial methodological advancements. The simplified method for water assessment by Bösch *et al*., (2007) is oriented toward theoretical cumulative energy demand, but does not account for regional differences related to water use. As stated above, such regional dependencies are essential for balancing water resources (Vörösmarty *et al*., 2005), particularly for products with a globalized value chain. Lundin & Morrison (2002) focused their LCA on urban water systems, and presented an impact assessment methodology suitable to urban water supply. Other studies, even when water supply is of central concern, simply place raw water extraction from aquifers beyond the system boundaries (e.g. Landu & Brent 2006).

Hydrological impact assessment is discussed in several studies (e.g. Shiklomanov, 1997; Vrba & Lipponen, 2007), but such judgments have not been incorporated in a LCA framework so far. The distance-to-target method of Ecological Scarcity 2006 accounts for regional aspects by assessing freshwater use on a country level (Frischknecht *et al*., 2008). National water-stress values are used to derive impact factors based on a defined threshold. While this method is a good first step to quantitatively assess potential water stress, it does not differentiate between water consumption (e.g. evaporation) and other water use (e.g. use of water as a cooling agent, returning the water to the watershed after use). Vince *et al*. (2008) describe an LCA approach for potable water production. However, effects such as reservoir depletion due to freshwater extraction or ecosystem impacts are not evaluated.

LCA of water use is closely related to virtual water principles and assignment of water footprints to products or countries (Chapagain & Hoekstra, 2004). The underlying idea is to quantify the total water that is needed within a lifecycle and thus, to calculate virtual water contents following a concept equivalent to LCA. However, and this is a fundamental difference, by only summarizing the water volumes spent during a product's life cycle, a general statement cannot be made about the severity of the related environmental impacts. In fact, virtual water volumes may be even misleading, by suggesting that water use and consumption is directly proportional to environmental burden. This rigorously ignores the regional dependencies of freshwater resources, and neglects the fact that water turnover and extraction can even be advantageous, such as in wet seasons or areas. For agricultural products, available virtual water databases represent comprehensive information sources, which report water requirements for several crops and countries. Still, these data cannot directly be used in LCA. For example, we need to quantify irrigation water and not total crop water requirements for tracking the water impacts from agriculture, as on-site precipitation is indirectly assessed by land use. In the following example, we demonstrate how such a conceptual modification influences the assessment.

EXAMPLE STUDY: GLOBAL WHEAT FARMING

Agricultural production is one of the most important economic activities and responsible for about 70% of the global anthropogenic freshwater withdrawals, while only 20% and 10% are used by industry and the municipalities, respectively (WB, 2004). Furthermore, freshwater scarcity has been recognized as one of the most crucial environmental issues (UNESCO, 2006) and several regions around the world are already facing this problem.

Global agriculture is facing substantial pressure from increased food and bio-energy demand affecting water and land availability. Globalized trade also requires global water resource management approaches, as local water management can hardly cope with the global market demand and its adverse effect on the producing regions. Conservation activities in one catchment might lead to greater water import from other regions where the pressure on water might be higher. In addition to focussing on optimal water resource management in single catchments, the global dimension of agricultural trade and embedded water has to be considered to arrive at meaningful assessments of water resource use. The key question is this: how can we optimize the water efficiency of crops and thereby minimize environmental impacts in the global context?

The virtual water concept and water footprint calculations are intended to tackle these questions. However, the underlying concept has so far been limited to the differentiation of blue (irrigation) and green (soil moisture) water. In order to account for the environmental impact caused by water use for crop production, we suggest calculating water deficiencies. The purpose of these calculations is to quantify the severity of the consumed water with respect to environmental issues and describe unsustainable water management involved in the production of a good. We developed a comprehensive environmental impact assessment method for water consumption which evaluates the damage potential regarding ecosystem and human health for major watershed levels worldwide (Pfister *et al.*, 2009). This assessment is based on a combination of different vulnerability studies and water scarcity measures with global coverage. A crop's content of "deficit water" is calculated by applying the resulting, spatially-resolved, impact factors on blue water data.

We computed regional irrigation requirements at a high level of spatial resolution (10 arc minutes grid), based on remote sensing data for the 50 globally most traded products. Deficit water footprints of crop production were generated for each grid cell, for each country and, based on FAO-based international trade data for the average product on the global market. For instance, one ton of wheat on the global market carries a virtual deficit water content of 0.23 m^3/kg and a virtual blue water content of 0.98 m^3/kg (Fig. 2). For the top ten wheat exporting countries, these values vary between 0.03 and 0.83 m^3/kg for deficit and 0.23 and 3.3 m^3/kg for blue water, respectively.

Figure 2 shows the global maps for the related impacts. These maps depict the differences of applying standard virtual water volumes and a deficit based approach. As expected, when considering deficit water, there is substantially higher impact in the dry regions of northern Africa and central Asia. In contrast, wheat production in countries such as Russia, Canada and Brazil is judged as more environmentally sound. In these countries, on the average, freshwater resources are sufficient and thus less threatened by intense agricultural activities. These discrepancies indicate the need for a more comprehensive impact-oriented perspective and the potential of global assessment approaches to support a balanced water management.

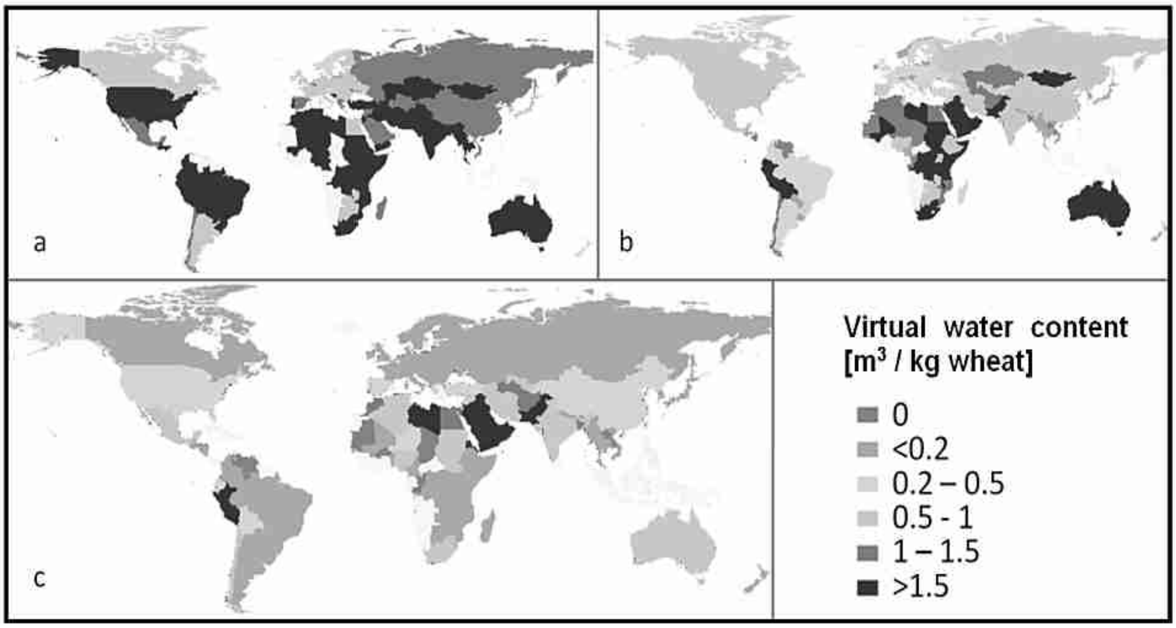

Fig. 2 Virtual water content of wheat: (a) total virtual water, (b) virtual blue water, and (c) virtual deficit water

CONCLUSIONS

The proposed contribution reviews the state of the art in a new interdisciplinary field: the integration of environmental assessment of freshwater use in Life Cycle Assessment (LCA). It is demonstrated that current concepts, such as standard water footprinting, have to be improved to reflect the true environmental burdens inherent to freshwater-demanding products. This is scrutinized by computing the standard and deficit virtual water contents of global wheat cropping. The new deficit-oriented perspective represents a promising and more plausible concept to identify those daily-life products of higher impacts.

Consumers, end or mid-point users and any protagonist of the global supply chain have the power of choice. Utilizing a realistic, hydrologically-based operational assessment method and including this into a common LCA-framework is essential to arrive at meaningful ecolabels or sustainability certifications. If we consider relative water deficits, we establish a direct connection to case-specific IWRM, and ultimately give control to any actor on the scene to exercise indirect water management. A standardized procedure and assessment of water in LCA further helps to illuminate additional and less subjective (e.g. political) aspects of water allocation problems.

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