

Chapter 4

Water Footprint Assessment in Supply Chains

Arjen Y. Hoekstra

4.1 Introduction

The World Economic Forum has listed water scarcity as one of the three global systemic risks of highest concern, an assessment based on a broad global survey on risk perception among representatives from business, academia, civil society, governments and international organisations (WEF 2014). Freshwater scarcity manifests itself in the form of declining groundwater tables, reduced river flows, shrinking lakes and heavily polluted waters, but also in increasing costs of supply and treatment, intermittent supplies and conflicts over water (Hoekstra 2014a). Future water scarcity will grow as a result of various drivers: population and economic growth, increased demands for animal products and biofuels and climate change (Ercin and Hoekstra 2014). The private sector is becoming aware of the problem of freshwater scarcity but is facing the challenge of formulating effective responses. Even companies operating in water-abundant regions can be vulnerable to water scarcity, because the supply chains of most companies stretch across the globe. An estimated 22 % of global water consumption and pollution relates to the production of export commodities (Hoekstra and Mekonnen 2012). Countries such as the USA, Brazil, Argentina, Australia, India and China are big virtual water exporters, which means that they intensively use domestic water resources for producing export commodities. In contrast, countries in Europe, North Africa and the Middle East as well as Mexico and Japan are dominated by virtual water import, which means that they rely on import goods produced with water resources elsewhere. The water use behind those imported goods is often not sustainable, because many of the export regions overexploit their resources.

A.Y. Hoekstra (✉)
University of Twente, Enschede, The Netherlands
e-mail: a.y.hoekstra@utwente.nl

Increasingly, companies start exploring their water footprint, thereby looking at both their operations and supply chain. Key questions that industry leaders pose themselves are as follows: where is my water footprint located, what risks does water scarcity impose to my business, how sustainable is the water footprint in the catchments where my operations and supply-chain processes are located, where and how can water use efficiency be increased and what is good water stewardship? The demand for new sorts of data emerges, types of data that were usually not collected. The focus shifts from relatively simple questions—whether the company has got sufficient water abstraction permits and whether wastewater disposal standards are met—to the more pressing question: how the company actually contributes to the overexploitation and pollution of water resources, not only through its own facilities but through its supply chain as well. Having permits and meeting standards do not imply sustainability. Most experience with collecting the new sorts of data required and with addressing questions about good water stewardship is within the food and beverage sector, which depends most clearly on water. In other industries, the connection with water is not always clear, because it is indirect and mostly through the supply chain. The aim of this chapter is to introduce the water footprint concept, review experiences with water footprint assessment and reflect on future challenges.

In the next section, I will start with discussing and comparing three methods to trace resource use and pollution over supply chains: environmental footprint assessment (EFA), life cycle assessment (LCA) and environmentally extended input–output analysis. Next, I will discuss what new perspective the water footprint concept brings to the table, compared to the traditional way of looking at water use. In the third section, I will reflect on direct and indirect water footprints of the different sectors of the economy, with examples for two specific sectors: food and beverage and transport. In the last section, I will discuss future challenges, such as the issue of data gathering and reporting, the demand for water stewardship and greater product transparency and the need to establish water footprint benchmarks.

4.2 Footprints, Life Cycle Assessment and Input–Output Modelling

4.2.1 Methods to Trace Natural Resource Use and Pollution Over Supply Chains

Three different methods have been developed to analyse direct and indirect natural resource use and emissions in relation to products or economic sectors: EFA, LCA and environmentally extended input–output analysis (EE-IOA). All three methods have been applied also in the field of water, to trace direct and indirect water use and pollution over supply chains. Each of the three methods has its specific goal, approach and focus, but there are commonalities across the methods as well. They all focus on

understanding natural resource use and emissions along supply or value chains. EFA focuses on macro-questions on resource use sustainability, efficiency, equitability and security. LCA concentrates on the comparative analysis of environmental impacts of products. EE-IOA focuses on understanding how natural resource use and environmental impacts can be traced throughout the economy.

The field of EFA comprises methods to quantify and map land, water, material, carbon and other environmental footprints and assess the sustainability of these footprints as well as the efficiency, equitability and security of resource use (Hoekstra and Wiedmann 2014). Water footprint assessment (WFA) can be regarded as a specific branch of this field and refers to the full range of activities to quantify and locate the water footprint of a process, product, producer or consumer or to quantify in space and time the water footprint in a specified geographic area; assess the environmental sustainability, economic efficiency and social equitability of water footprints; and formulate a response strategy (Hoekstra et al. 2011). Broadly speaking, the goal of assessing water footprints is to analyse how human activities or specific products relate to issues of water scarcity and pollution and to see how consumption, production, trade and specific products can become more sustainable from a water perspective.

LCA is a method for estimating and assessing the environmental impacts attributable to the life cycle of a product, such as climate change; stratospheric ozone depletion; tropospheric ozone (smog) creation; eutrophication; acidification; toxicological stress on human health and ecosystems; the depletion of resources, water use, land use and noise; and others (Rebitzer et al. 2004). The assessment includes all stages of the life cycle of a product, from cradle to grave (from material extraction to returning of wastes to nature). An LCA study includes four phases: setting goal and scope, inventory accounting, impact assessment and interpretation. Water use and pollution can be considered as specific impact categories within LCA (Kounina et al. 2013). LCA focuses on *comparing* the environmental impacts of alternative processes, materials, products or designs. (See Chap. 2 by Guinée and Heijungs (2017) for more on LCA.)

Environmentally extended input–output analysis (EE-IOA) is a method for studying the relation between different sectors of the economy and indirect natural resource use and environmental impacts. It combines the classical monetary input–output formalism with satellite accounts containing data on resource use and emissions into the environment. Over the past decade, we have seen quite a number of applications of EE-IOA to analyse ‘embodied’ water flows through the economy (Daniels et al. 2011). Applications have been carried out, for example, for Australia (Lenzen and Foran 2001), Spain (Duarte et al. 2002; Cazarro et al. 2013), the UK (Yu et al. 2010; Feng et al. 2011a), China (Zhao et al. 2009; Zhang and Anadon 2014) and the city of Beijing (Zhang et al. 2011). Input–output models basically show monetary flows between sectors within the economy; environmentally extended input–output models usually express water use in terms of litre per dollar (or other currencies). Most environmentally extended input–output models also have some form of accounting of product flows in physical units, but due to the aggregation of specific economic activities into sectors, it remains difficult to reach

the same high level of detail as achieved in a process-based WFA or LCA. Both WFA and LCA enable an analysis of water use in all processes of the value chain and attribution of the water use along value chains to specific products. A promising path in this respect is the method of so-called *hybrid* environmentally extended input–output modelling, in which physical flows are integrated into the model (Ewing et al. 2012; Steen-Olsen et al. 2012).

Process-based WFA and LCA are generally constrained by the fact that parts of the value chain have to be left out from the analysis for practical reasons. This problem does not occur in input–output modelling. Therefore, there is a development to enhance process-based WFA and LCA with the advantage of input–output modelling. In the case of LCA, this results in the so-called hybrid LCA approach (Finnveden et al. 2009). In hybrid LCA, the environmental impacts of flows that were not included in the process-based LCA are estimated with an environmentally extended input–output model. This hybrid approach is also called environmental input–output-based LCA (EIO-LCA). In the case of WFA, a similar development can be expected (Feng et al. 2011b).

The difference between EFA and LCA is the focus on sustainability of production and consumption at macro-level of the former and the focus on comparing environmental impact at process and product level of the latter (Hoekstra 2015b). This is explained in Box 4.1 for the example of cutting trees. Typical questions in EFA studies relate to how different processes and products contribute to the overall footprints at larger scales, how different consumption patterns influence the overall footprint, whether footprints at the larger scales remain within their maximum sustainable levels, how footprints can be reduced by better technology, whether different people have equitable shares in the total footprint of humanity and what externalisation of footprints may imply for resource security (Hoekstra and Wiedmann 2014). LCA is designed to compare the environmental impact of one product over its full value chain with the overall impact of another product or to compare the differences in environmental impact between different product designs or alternative production processes.

Box 4.1 The Sustainability of Cutting Trees: The Fundamental Difference Between LCA and EFA

Is it sustainable to cut a tree? Although a relevant question, it is impossible to answer this question in isolated form. On the one hand, it is hard to argue that cutting just one tree is not sustainable. After a tree has been cut, a new one will grow, so that is sustainable. On the other hand, if one takes this insight on the sustainability of cutting one tree to conclude that one can cut all forests, one cannot maintain that this is sustainable. The reason why answering a simple question like this tree-cutting question causes a fundamental problem is that sustainability is a concept that cannot be applied at the level of single

(continued)

Box 4.1 (continued)

activities, but only at the level of a system as a whole. Still, there is a strong wish among people to measure the sustainability of single activities, because individuals undertake single activities and consume goods and services that relate to series of single activities to produce them. The methods of LCA and EFA deal with this problem in fundamentally different ways. In LCA, the approach is to leave the larger question on sustainability and look at *comparative* contributions of different activities to natural resource appropriation, emissions and potential impacts at the larger scale. In other words, LCA addresses the question how cutting one tree compares to cutting two trees, a question that is not hard to answer. In EFA, the approach is to estimate humanity's total natural resource appropriation and emissions and compare that to the Earth's carrying or assimilation capacity. Both methods struggle in a similar way with how to compare apples and pears, for example, how to compare cutting trees with polluting water. The approach in LCA is to *weigh* different types of primary resource use or emissions according to their potential final impact on human health and ecosystem health. The approach in EFA is to compare the different types of resource use and pollution to their respective maximum sustainable levels. The great similarity between LCA and EFA is that resource use and emissions are analysed per process (activity) and per product (by analysing the processes along supply chains). The difference comes when LCA starts weighing different types of resource use and emissions based on their potential impact and comparing alternative processes or products according to their overall potential environmental impact. In contrast, EFA adds the resource use and emissions of different activities in order to get a complete picture, analyse the sustainability of the whole and study the relative contribution of different processes, products and consumers to the total. In many applications, though, the difference between LCA and EFA is not so clear. By comparing the footprints of two different processes or products, EFA also allows for comparative analysis. However, the comparative analysis is partial in this case, because different footprints are not weighted and added to get a measure of 'overall potential environmental impact'. On the other hand, one can also extend an LCA from comparing products to comparing consumption patterns, which is at the larger scale typically for EFA. The fundamental difference between LCA and EFA in the way they treat the tree-cutting question, however, remains.

At the level of basic data, EFA and LCA require similar data. The data collection and analysis required in the accounting stage of a product-focused WFA (as opposed to a geographic- or consumption-focused WFA) are very much similar to what is needed in the inventory stage of a water-focused LCA (Boulay et al. 2013).

EFA, LCA and EE-IOA are not static analytical methods, but still young fields under development. We can observe a development in the past few years in which a

fruitful exchange between the three fields leads to the adoption of approaches from one field into the other. In EFA studies we have seen the adoption of life cycle accounting procedures from LCA and the exploration of using input–output models to calculate national and sector footprints, in addition to the already existing bottom-up and top-down trade-balance approaches. In LCA we recently observe, fed by experiences in EFA, an interest to develop methods to carry out an LCA for a whole organisation instead of for a product and to carry out LCAs for consumer lifestyles or for national consumption as a whole (Hellweg and Milà i Canals 2014). Additionally, based on experiences in EE-IOA, the LCA community is exploring hybrid LCA methods as already mentioned above. The EE-IOA practice improves in the direction of hybrid methods that include physical accounting and have greater granularity in the analysis, fed by the practices in the EFA and LCA fields. This mutual enrichment and to some extent convergence of approaches do not imply that the three methods will grow into one. They may develop into a more consistent framework of coherent methods, but the fact that different sorts of questions will remain implies that different approaches will continue to be necessary.

All three methods—EFA, LCA and EE-IOA—have a focus on environmental issues, leaving out social issues (like labour conditions, human rights). Principally, though, there is nothing that necessarily restricts the methods to environmental issues. Broadly speaking, one can trace all sorts of process characteristics along supply chains. The oldest forms of accounting along supply chains are the accounting of monetary added value and the accounting of material flows and energy use along supply chains. Material flow analysis (MFA) or substance flow analysis (SFA) aims at the quantification of stocks and flows of materials or substances in a well-defined system, drawing mass balances for each subsystem and the system as a whole. Energy flow analysis aims at quantifying the energy content of flows within an economy. The innovation of EFA, LCA and EE-IOA lies in the attribution of resource use, emissions or impacts along supply chains to products and final consumption. In this context, one speaks about the embodied, embedded, indirect or virtual land, water and energy in a product or consumption pattern, the indirect emissions, etc. When doing so, the method of EE-IOA is linked to traditional economic accounting, which is a strong point of this method. The methods of EFA and LCA are rather linked to physical accounting, which is their strength. In all three fields, we observe efforts to enhance the methods and broaden the scope, with an increasing number of hybrid approaches.

4.2.2 The Water Footprint Concept

The water footprint (WF) is a measure of freshwater appropriation underlying a certain product or consumption pattern. Three components are distinguished: the blue, green and grey WF (Hoekstra et al. 2011). The blue WF measures the volume of water abstracted from the ground or surface water system minus the volume of water returned to the system. It thus refers to the sum of the water flow that

evaporates during the process of production, the water incorporated into a product and the water released in another catchment. The blue WF differs from the conventional way of measuring freshwater use by looking at net rather than gross water withdrawal. This is done because it makes more sense to look at net water withdrawal if one is interested in the effect of water use on water scarcity within a catchment. Return flows can be reused within the catchment, unlike the water flow that evaporates or is captured within a product. The green WF refers to the volume of rainwater consumed in a production process. This is particularly relevant in agriculture and forestry, where it refers to the total rainwater evapotranspiration (from fields and plantations) plus the water incorporated into the harvested crop or wood. The grey WF is an indicator of freshwater pollution and defined as the volume of freshwater required to assimilate a load of pollutants based on natural background concentrations and existing ambient water quality standards. The advantage of expressing water pollution in terms of the water volume required for assimilating the pollutants, rather than in terms of concentrations of contaminants, is that this brings water pollution into the same unit as consumptive use. In this way, the use of water as a drain and the use of water as a resource, two competing uses, become comparable. The WF refers thus to both consumptive water use (of rainwater—the green WF—and of surface and groundwater—the blue WF) and degenerative or degradative water use (the grey WF).

As a measure of freshwater use, the WF differs from the classical measure of ‘water withdrawal’ in several ways. The term ‘water withdrawal’—also called ‘water abstraction’ or often simply ‘water use’—refers to the extraction of water from the groundwater or a surface water body like a river, lake or artificial storage reservoir. It thus refers to what we call *blue* water use. The WF is not restricted to measuring blue water use, but also measures the use of green water resources (the green WF) and the volume of pollution (the grey WF). Another difference between the WF and the classical way of measuring water use was mentioned already above: the classical measure of ‘water use’ always refers to gross blue water abstraction, while the blue WF refers to net blue water abstraction. Another difference between the classical way of measuring water use and the WF is that the latter concept can be used to measure water use over supply chains. When we talk about the WF of a product, we refer to the water consumption and pollution in all stages of the supply chain of the product. When we speak about the WF of a producer or a consumer, we refer to the full WF of all the products produced or consumed.

The WF thus offers a wider perspective on how a product, producer or consumer relates to the use of freshwater systems. It is a volumetric measure of water consumption and pollution. WF accounts give spatiotemporally explicit information on how water is appropriated for various human purposes. The local environmental impact of a certain amount of water consumption and pollution depends on the vulnerability of the local water system and the number of water consumers and polluters that make use of the same system. The WF within a catchment needs to be compared to the maximum sustainable WF in the catchment in order to understand the sustainability of water use. The WF of a specific process or product needs to be compared to a WF benchmark based on best available technology and practice in

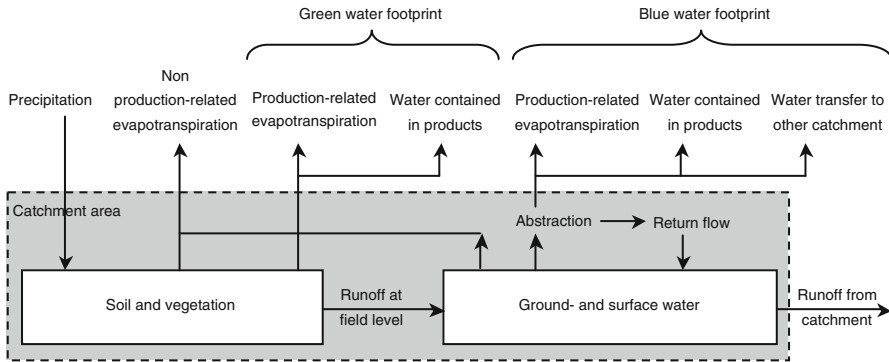


Fig. 4.1 Definition of the green and blue water footprint in relation to the water balance of a catchment area. *Source:* Hoekstra et al. (2011)

order to understand the efficiency of water use. The WF per capita for a community can be compared to the WF of other communities to understand the degree of equitable sharing of limited water resources. WF accounts can thus feed the discussion about the sustainability, efficiency and equitability of water use and allocation (Hoekstra 2013, 2014b).

The definition of the green and blue WF can best be understood by considering the water balance of a river basin (Fig. 4.1). The total annual water availability in a catchment area is given by the annual volume of precipitation, which will leave the basin partly through evapotranspiration and partly through runoff to the sea. Both the evaporative flow and the runoff can be appropriated by humans. The green WF refers to the human use of the evaporative flow from the land surface, mostly for growing crops or production forest. The blue WF refers to the consumptive use of the runoff flow, i.e. the net abstraction of runoff from the catchment. The term ‘water consumption’ can be confusing, because many people—particularly those not aware of the big difference between gross and net water abstraction—use the term for gross water abstraction. Specialists, though, define water consumption as net blue water abstraction (gross abstraction minus return flow). Evaporation is generally considered as a loss to the catchment. Even though evaporated water will always return in the form of precipitation at global scale, this will not alleviate the water scarcity in the catchment in the period that the river is emptied due to net water abstractions. Moisture recycling at smaller spatial scales is generally only modest.

The definition of the grey WF is clarified in Fig. 4.2. The basis for the calculation is the anthropogenic load of a substance into a freshwater body (groundwater, river, lake), that is, the additional load caused by a human activity (e.g. a production process). We should acknowledge that the effluent from an industry might contain certain amounts of chemicals that were already in the water abstracted. Therefore, we should look at the *additional* load to a freshwater body as a result of a certain activity. Furthermore, we should look at the load of a substance that really enters the river, lake or groundwater, which means that, if an effluent is treated before disposal, we have to consider the load of chemicals in the effluent that remains *after* treatment.

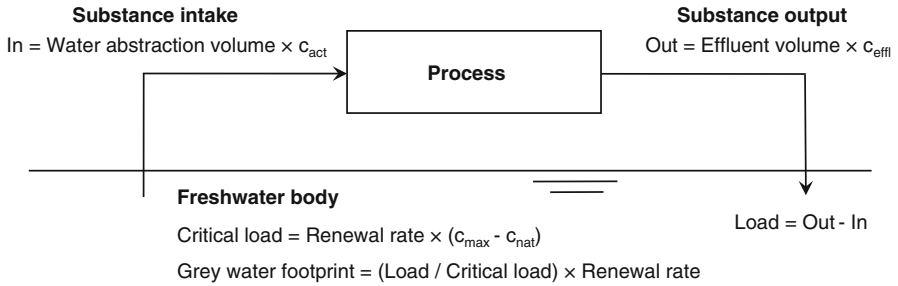


Fig. 4.2 Definition of the grey water footprint based on the load of a chemical into a freshwater body. The symbols c_{act} , c_{nat} and c_{max} refer to the actual, natural and maximum allowable concentration of the chemical in the freshwater body; c_{eff} refers to the concentration of the chemical in the effluent

The critical load in a freshwater body is defined as the difference between the maximum acceptable and natural concentration of a chemical for the receiving water body times the renewal rate of the freshwater body. Note that as for the maximum allowable concentration, we have to take the ambient water quality standard for the receiving freshwater body, not the effluent standard (Franke et al. 2013). In a river, the renewal rate is equal to runoff; in a groundwater reservoir, the renewal rate is equal to groundwater recharge, which (over the longer term) is the same as groundwater runoff. In a lake, the renewal rate equals the flow through the lake. The grey WF is calculated as the pollutant load to a freshwater body divided by the critical load, times the renewal rate of that freshwater body. Defined in this way, it means that when the grey WF onto a freshwater body becomes as big as the renewal rate of this freshwater body, the assimilation capacity has been fully used. When the size of the grey WF in a catchment exceeds the size of runoff from this catchment, pollution is bigger than the assimilation capacity, resulting in a violation of the maximum acceptable concentration. When an effluent contains different sorts of pollutants, as is usually the case, the grey WF is determined by the pollutant that is most critical, that is the one that gives the largest pollutant-specific grey WF. Thermal pollution can be dealt with in a similar way as pollutants, whereby the load consists of heat and the assimilation capacity depends on the accepted temperature increase of the receiving water body (Hoekstra et al. 2011).

4.3 Direct and Indirect Water Footprints of Different Sectors of the Economy

4.3.1 The Importance of Water Use in the Primary Sector

Usually, economic activities are categorised into three different sectors. The primary sector of the economy, the sector that extracts or harvests products from the earth, has the largest water footprint on Earth. This sector includes activities like

Table 4.1 Global water footprint within different water-using categories (period: 1996–2005)

Economic sector	Water use category	Global water footprint (10 ⁹ m ³ /year)					Remark
		Green	Blue	Grey	Total	%	
Primary sector	Crop farming	5771	899	733	7404	81.5	
	Pasture	913	–	–	913	10.0	
	Animal farming	–	46	–	46	0.5	Water for drinking and cleaning
	Agriculture total	6684	945	733	8363	92.0	
	Aquaculture	?	?	?	?	?	No global data
	Forestry	?	?	?	?	?	No global data
	Mining, quarrying	?	?	?	?	?	No global data
Secondary sector	Industry (self-supply)	–	38	363	400	4.4	Water use in manufacturing, electricity supply and construction
	Municipal water supply	–	42	282	324	3.6	Water supply to households and (small) users in primary, secondary and tertiary sector
Tertiary sector	Self-supply	?	?	?	?	?	No global data
Households	Self-supply	?	?	?	?	?	No global data
Total		6684	1025	1378	9087	100	

Data sources: Mekonnen and Hoekstra (2011) for crop farming; Mekonnen and Hoekstra (2012) for pasture and animal farming; Hoekstra and Mekonnen (2012) for industry and municipal water supply

Note that the blue WF figure for crop farming relates to evapotranspiration of irrigation water at field level; it excludes losses from storage reservoirs and irrigation canals

The blue WF figure for ‘industry’ presented here includes water use in mining, which is part of the primary sector

The figure excludes water lost from reservoirs for hydroelectric generation

All grey WF figures are conservative estimates

Forestry is not included as a water use sector because of a lack of data

agriculture, forestry, fishing, aquaculture, mining and quarrying. The green WF of humanity is nearly entirely concentrated within the primary sector. It has been estimated that about 92 % of the blue WF of humanity is just in agriculture alone (Table 4.1).

The secondary sector covers the manufacturing of goods in the economy, including the processing of materials produced by the primary sector. It also includes construction and the public utility industries of electricity, gas and water. Sometimes, the public utility industries are also mentioned under the tertiary (service) sector, because they do not only produce something (electricity, gas, purified water), but also supply it to customers (as a service). Water utilities could even partly fall under the primary sector, because part of the activity is the abstraction of water from the environment (rivers, lakes, groundwater). The work of water utilities comprises

water collection, purification, distribution and supply, wastewater collection (sewerage), wastewater treatment, material recovery and wastewater disposal. It's rather common to categorise the whole water utility sector under the secondary sector. The tertiary industry is the service industry and covers services to both businesses and final consumers. This sector includes activities like retail and wholesale sales, transportation and distribution, entertainment, restaurants, clerical services, media, tourism, insurance, banking, healthcare, defence and law. Even though sometimes categorised into another, quaternary sector, one can also list here activities related to government, culture, libraries, scientific research, education and information technology. The secondary and tertiary sectors have much smaller WFs than the primary sector.

The contribution of agriculture to water scarcity is underestimated by conventional water use statistics, which show gross blue water abstractions. In agriculture, most of the gross water use will evaporate from storage reservoirs, irrigations canals or finally from the field. The water abstracted for irrigation in agriculture is thus largely unavailable for reuse within the basin. In industrial water use, the ratio of net to gross abstraction is estimated at less than 5%. In municipal water use, this ratio varies from 5 to 15% in urban areas and from 10 to 50% in rural areas (FAO 2014). Water that returns to the catchment after use can be reused. Presenting gross or net water abstractions thus makes a huge difference for industries and households and less in agriculture.

Even though the primary sector is the largest water user, governmental programmes to create public awareness of water scarcity often focus on public campaigns calling for water saving at home. This is little effective at large given the fact that the major share of water use in most places relates to agriculture and in second instance to industry. Water scarcity is thus generally caused mostly by excessive water use in agriculture. Installing water-saving showerheads and dual-flush toilets in households will have hardly any impact in mitigating water scarcity at all, but still this is what most water-saving campaigns advocate for. It would be more useful to make people aware of the water use and pollution underlying the food items and other products they buy and to advocate for product labels that show the sustainability of the WF of a product.

4.3.2 Food and Beverage Products

The food and beverage sector is the manufacturing sector with the largest WF, maybe not the largest operational WF, but definitely the largest supply-chain WF. (Chap. 18 by Bloemhof and Soysal (2017) focuses on designing sustainable food supply chains.) The reason is that the food and beverage sector is the largest client of the agricultural sector, which is responsible for the largest share in global water consumption (Table 4.1). Interesting WF studies carried out in the beverage sector are, for example, the studies carried out by SABMiller (SABMiller and WWF-UK 2009; SABMiller et al. 2010), Coca-Cola (TCCC and TNC 2010; Coca-Cola

Europe 2011) and the Beverage Industry Environmental Roundtable (BIER 2011). Some nice examples of WF studies in the food sector come from Unilever (Jefferies et al. 2012), Dole (Sikirica 2011), Mars (Ridoutt et al. 2009) and Barilla (Ruini et al. 2013).

Traditionally, the beverage industry focuses on the so-called water use ratio (WUR), which is defined as the total water use divided by the total production at a bottling facility, expressed in terms of litre of water used per litre of beverage produced. Water use stands here for gross blue water abstraction, not net blue water abstraction (blue WF). In a global benchmarking study for the period 2009–2011, BIER (2012) reports a WUR of 1.2–2.2 L/L (with an average of 1.5) for bottled water, a WUR of 1.5–4.0 (average 2.1) for carbonated soft drinks, a WUR of 3.2–6.6 (average 4.3) for beer breweries, a WUR of 8–126 (average 36) for distilleries and a WUR of 2.0–18.5 (average 4.4) for wineries. The WUR is of limited value, because the operational WF of bottling factories is very small when compared to the full WF of a beverage, as shown by Ercin et al. (2011) for a carbonated soft drink. They show that the WF of a half-litre bottle of soft drink resembling cola can range between 150 and 300 L, of which 99.7–99.8% refers to the supply chain.

4.3.3 *Transport*

Transport is always considered as an important sector in carbon footprint assessment, since transport can significantly contribute to the overall carbon footprint of a final product, measured over its full supply chain. In the case of the WF of a final product, the contribution of transport will generally be relatively small, because not much freshwater is being consumed or polluted during transport. It is worth considering the indirect WF of transport related to materials (trucks, trains, boats, airplanes) and energy used, but particularly materials will generally contribute very little, due to the fact that the WF of transport vehicles can be distributed over all goods transported over the lifetime of a vehicle. The WF of energy may be more relevant, but even that can be small compared to the other components of the WF of goods, particularly in the case of agricultural goods. The key determinant in the WF of transport is probably the energy source (Gerbens-Leenes et al. 2009a; King and Webber 2008). The WF of bioenergy in terms of cubic metre per GJ is generally two to three orders of magnitude larger than that for energy from fossil fuels or wind or solar power. However, in all energy categories, WFs per unit of energy can widely vary, depending on the precise source and production technology. The technique of hydraulic fracturing (fracking) to mine natural gas or petroleum reserves, for example, has a larger blue and grey WF than when mining reserves that are easier accessible using more conventional techniques. In the case of bioenergy, it matters greatly whether one speaks about biodiesel from oil crops, bioethanol from sugar or starch crops (Gerbens-Leenes et al. 2009b; Dominguez-Faus et al. 2009), biofuel from cellulosic fractions of crops or waste materials (Chiu and Wu 2012), biofuel from algae (Gerbens-Leenes et al. 2014) or about bioelectricity. In the latter case,

Table 4.2 The water footprint of different modes of passenger and freight transport when based on first-generation biofuel produced in the European Union

Transport mode	Energy source	Green + blue water footprint of passenger transport (L per passenger km)	Green + blue water footprint of freight transport (L per 1000 kg of freight per km)
Airplane	Biodiesel from rapeseed	142–403	576–1023
	Bioethanol from sugar beet	42–89	169–471
Car (large)	Biodiesel from rapeseed	214–291	–
	Bioethanol from sugar beet	138–289	–
Car (small)	Biodiesel from rapeseed	65–89	–
	Bioethanol from sugar beet	24–50	–
Bus/lorry	Biodiesel from rapeseed	67–126	142–330
	Bioethanol from sugar beet	20–58	–
Train	Biodiesel from rapeseed	15–40	15–40
Ship (inland)	Biodiesel from rapeseed	–	36–68
Ship (sea, bulk)	Biodiesel from rapeseed	–	8–11
Electric train	Bioelectricity from maize	3–12	2–7
Electric car	Bioelectricity from maize	4–7	–
Walking	Sugar from sugar beet	3–6	–
Bike	Sugar from sugar beet	1–2	–

Source of data: Gerbens-Leenes and Hoekstra (2011)

The total water footprint of transport based on first-generation biofuel mainly relates to the water volumes consumed in growing the crop

it makes a large difference what is burnt: biomass grown for the purpose or organic waste. As an illustration of the large differences between different bioenergy forms, Table 4.2 shows the WF of different modes of passenger and freight transport when based on first-generation biofuel produced in the European Union. Governmental policies to replace substantial percentages of fossil fuels by biofuels will lead to a rapid growth of the WF of the transport sector (Gerbens-Leenes et al. 2012).

4.4 Challenges

4.4.1 The Need to Take a Supply-Chain Perspective

The supply-chain WF of most companies is many times greater than their operational footprint, but most companies restrict their efforts to reducing the latter, leaving the supply-chain WF out of scope. Studies carried out by companies like Coca-Cola, PepsiCo, SABMiller and Heineken have shown that the supply-chain WF for beverage companies can easily be over 99% of their total WF. Nevertheless, all these companies apply a ‘key performance indicator’ for water that refers to the water use in their own operations only. Common reduction targets in the beverage industry,

such as going from 2 to 1.5 L of water use in the bottling plant per litre of beverage, have little effect on the larger scale given that the supply-chain WF of most beverages is of the order of 100 L of water per litre of beverage or even more (Hoekstra 2013). Water-sustainability investments by beverage companies are geared to better perform in their own operations, which means that investments are made that aim to reduce that one per cent of their total WF. It is difficult to imagine that these investments will be most cost effective if really sustainability is the goal. Incorporating sustainability principles into a company's business model would include the adoption of mechanisms to secure sustainable water use in the supply chain. For companies, moving towards a sustainable supply chain is a much bigger challenge than greening their own operations, because the WF of the supply chain can be influenced only indirectly. Mechanisms to reduce the supply-chain WF are, for example, the application of water criteria for sustainable procurement and reaching agreements with suppliers about footprint reduction over time.

4.4.2 *The Need to Incorporate Temporal and Spatial Variability in Water Footprint Assessment*

When formulating WF reduction targets for processes in their operations or supply chain, companies should not only look at the numbers but also at the geographic locations where their WF is sited. Priority is to be given to WF reduction in catchments in which the overall footprint exceeds the carrying capacity or assimilation capacity of the catchment. It has been argued that reduction in water-abundant catchments does not even make sense (Pfister and Hellweg 2009), but this is based on a misunderstanding. Since the WF ($\text{m}^3/\text{product unit}$) is simply a reverse of water productivity (product units per m^3), it is difficult to see why one would not set targets regarding the reduction of the WF of a product, which is the same as setting targets regarding the increase of water productivity. The relevance of increased water productivities worldwide, also in water-abundant places, can be illustrated with the following example (Hoekstra 2013). Suppose the hypothetical case of two river basins, with the same surface (Table 4.3). Basin A is relatively dry and has, on

Table 4.3 Example of how overexploitation in a water-stressed river basin (A) can be solved by increasing water productivity in a water-abundant basin (B)

Parameter	Unit	Current situation		Possible solution	
		Basin A	Basin B	Basin A	Basin B
Max. sustainable water footprint	Water units/unit of time	50	250	50	250
Water footprint	Water units/unit of time	100	200	50	200
Production	Product units/unit of time	100	100	50	200
Water footprint per product unit	Water units/product unit	1	2	1	1
Water productivity	Product units/water unit	1	0.5	1	1

Source: Hoekstra (2013)

an annual basis, 50 water units available, the maximum sustainable WF. The maximum level, however, is exceeded by a factor of two. Farmers in the basin consume 100 water units per year to produce 100 crop units. Basin B has more water available, 250 water units per year. Water is more abundant than in the first basin, but water is used less efficiently. Farmers in the basin consume 200 water units per year, to produce 100 crop units, the same amount as in the first basin, but using two times more water per crop unit. A geographic analysis shows that in basin B, the WF (200) remains below the maximum level (250), so this is sustainable. In basin A, however, the WF (100) by far exceeds the maximum sustainable level (50), so this is clearly unsustainable. The question is now: should we categorise the crops originating from basin A as unsustainable and the crops from basin B as sustainable? From a geographic perspective, the answer is affirmative. In basin A, the WF of crop production needs to be reduced that seems to be the crux. However, when we take a product perspective, we observe that the WF per crop unit in basin B is two times larger than in basin A. If the farmers in basin B would use their water more productively and reach the same water productivity as in basin A, they would produce twice as many crops without increasing the total WF in the basin. It may well be that farmers in basin A cannot easily further increase their water productivity, so that—if the aim is to keep global production at the same level—the only solution is to bring down the WF in basin A to a sustainable level by cutting production by half, while enlarging production in basin B by increasing the water productivity. If basin B manages to achieve the same water productivity level as in basin A, the two basins together could even increase global production while halving the total WF in basin A and keeping it at the same level in basin B.

4.4.3 Measuring and Reporting

It is difficult to get water use statistics organised along the same structure of economic sector classifications. Many countries and regions have their own classification of economic activities, distinguishing main sectors, subsectors, etc. One of the international standard classifications is the Industrial Classification of All Economic Activities of the United Nations (UN 2008). Conventional water use statistics mostly show gross blue water withdrawals and distinguish three main categories: agricultural, industrial and municipal water use (FAO 2014). Also WF statistics distinguish between the agricultural, industrial and municipal sector. These three sectors cannot be mapped one to one onto the primary, secondary and tertiary sector. ‘Agricultural water use’ obviously is about water use in the primary sector, while ‘industrial water use’ is about water use in the secondary sector. However, water use in mining—part of the primary sector—will generally be categorised under ‘industrial water use’ as well. Industrial water use refers to self-supplied industries not connected to the public distribution network. It includes water for the cooling of thermoelectric plants, but it does not include hydropower (which is often left out of the water use accounts altogether). Municipal water use—often alternatively called domestic water use or public water supply—refers to the water use by water utilities

and distributed through the public water distribution network. Water utilities provide water directly to households, but also to water users in the primary, secondary and tertiary sector.

The mismatch between the three main categories in water use statistics and the different sectors as usually distinguished in the economy can be quite confusing. The ‘water supply sector’ as distinguished in economic classifications refers to water utilities delivering municipal water to households and others connected to the public water supply system. Unfortunately, the category of municipal water use lumps water use for a great variety of water users: final consumers (households) and users in all economic sectors. Specifications by type of user are not always available. Additionally confusing is that, even though the ‘water supply sector’ serves all sorts of users, the sector refers to only a minor fraction of total water use. Most of the water use in agriculture, the largest water user, is not part of the ‘water supply sector’. Furthermore, water self-supply by industries does not fall within this sector and neither does self-supply in the tertiary sector and self-supply by final consumers. Given that only an estimated 3.6% of the total WF of humanity relates to what we call the ‘water supply sector’ (Hoekstra and Mekonnen 2012), the sector receives disproportionate attention in public debates about water use and scarcity, diverting the necessary attention on water use in agriculture and industry.

For companies, much confusion exists as to what needs to be measured and reported. Traditionally, companies have focused on monitoring gross water abstractions and compliance with legal standards. However, net water abstractions are more relevant than gross abstractions, and meeting wastewater quality standards is not enough to discard the contribution to water pollution made by a company. Regarding terminology and calculation standards, the Water Footprint Network—a global network of universities, nongovernmental organisations, companies, investors and international organisations—developed the global water footprint standard (Hoekstra et al. 2011). The International Organization for Standardization developed a reporting standard based on LCA (ISO 2014). Both standards emphasise the need to incorporate the temporal and spatial variability in WFs and the need to consider the WF in the context of local water scarcity and water productivity. In practice, companies face a huge challenge in tracing their supply chain. Apparel companies, for example, have generally little idea about where their cotton is grown or processed, yet both cotton growing and processing are notorious water consumers and polluters. It is difficult to see quick progress in the field of supply-chain reporting if governments don’t force companies to do it.

4.4.4 Water Stewardship and Transparency

There is an increasing call for good water stewardship and transparency in the private sector, driven by increased public awareness, demands from investors and perceived water risks by the sector itself. Water stewardship is a comprehensive concept that includes the evaluation of the sustainability of water use across the

entire value chain, the formulation of water consumption and pollution reduction targets for both the company's operations and supply chain, the implementation of a plan to achieve these targets and proper reporting on all of this (Hoekstra 2014a). In priority catchments, it requires the pursuit of collective action and community engagement (Sarni 2011). Large priority river basins are, for example, the Colorado and San Antonio basins in North America; the Lake Chad, Limpopo and Orange basins in Africa; the basins of the Jordan, Tigris, Euphrates, Indus, Ganges, Krishna, Cauvery, Tarim and Yellow rivers; the Yongding River basins in Asia; and the Murray–Darling basin in Australia (Hoekstra et al. 2012).

The increasing interest in how companies relate to unsustainable water use calls for greater transparency on water consumption and pollution. Openness is required at different levels: the company, product and facility level. Driven by environmental organisations and the investment community, businesses are increasingly urged to disclose relevant data at company level on how they relate to water risks (Deloitte 2013). Simultaneously, there is an increasing demand for product transparency through labelling or certification. Despite the plethora of existing product labels related to environmental sustainability, none of these includes criteria on sustainable water use. Finally, there is a movement to develop principles and certification schemes for sustainable site or facility management, such as the initiatives of the European Water Partnership and the Alliance for Water Stewardship. But despite progress in awareness, still hardly any companies in the world report on water consumption and pollution in their supply chain or reveal information about the sustainability of the WF of their products.

Another concern regarding good water stewardship is the extent to which a company pays for the full cost of its water use. Water use is subsidised in many countries, either through direct governmental investments in water supply infrastructure or indirectly by agricultural subsidies, promotion of crops for bioenergy or fossil-energy subsidies to pump water. Besides, water scarcity and pollution remain unpriced (Hoekstra 2013). In order to give the right price signal, users should pay for their pollution and consumptive water use, with a differentiated price in time and space based on water vulnerability and scarcity.

4.4.5 The Need to Establish WF Benchmarks

WFs per unit of product strongly vary across different production locations and production systems. Therefore we need to establish WF benchmarks for water-intensive products such as food and beverages, cotton, flowers and biofuels. The benchmark for a product will depend on the maximum reasonable water consumption in each step of the product's supply chain, based on best available technology and practice. Benchmarks for the various water-using processes along the supply chain of a product, can be taken together to formulate a WF benchmark for the final product. An end-product point of view is particularly relevant for the companies, retailers and consumers who are not directly involved in the water-using processes

in the early steps of the supply chains of the products they are manufacturing, selling or consuming, but still interested in the water performance of the product over the chain as a whole. WF benchmarks will offer a reference for companies to work towards and a reference for governments in allocating WF permits to users. Besides, manufacturers, retailers and final consumers in the lower end of the supply chain get an instrument to compare the actual WF of a product to a certain reference level. Business associations within the different sectors of economy can develop their own regional or global WF benchmarks, though governments can take initiatives in this area as well, including the development of regulations or legislation. The latter will be most relevant to completely ban worst practices.

4.4.6 Water Footprint Reduction Goals and Possible Trade-Offs

Companies should strive towards zero WF in industrial operations, which can be achieved through nullifying evaporation losses, full water recycling and recapturing chemicals and heat from used water flows. The problem is not the fact that water is being used, but that it is not fully returned to the environment or not returned clean. The WF measures exactly that: the consumptive water use and the volume of water polluted. As the last steps towards zero WF may require more energy, the challenge will be to find a balance between reducing the water and the carbon footprint. Furthermore, companies should set reduction targets regarding the WF of their supply chain, particularly in areas of great water scarcity and in cases of low water productivity. In agriculture and mining, achieving a zero WF will generally be impossible, but in many cases the water consumption and pollution per unit of production can be reduced easily and substantially (Brauman et al. 2013).

4.5 Conclusion

Spatial patterns of water depletion and contamination are closely tied to the structure of the global economy. As currently organised, the economic system lacks incentives that promote producers and consumers to move towards wise use of our limited freshwater resources. In order to achieve sustainable, efficient and equitable water use worldwide, we need greater product transparency, international cooperation, water footprint ceilings per river basin, water footprint benchmarks for water-intensive commodities, water pricing schemes that reflect local water scarcity and some agreement about equitable sharing of the limited available global water resources among different communities and nations.

Acknowledgement This chapter is abridged and adapted from Hoekstra (2015a).

References

- BIER (2011) A practical perspective on water accounting in the beverage sector. Beverage Industry Environmental Roundtable. www.waterfootprint.org/Reports/BIER-2011-WaterAccountingSectorPerspective.pdf. Accessed 4 Aug 2014
- BIER (2012) Water use benchmarking in the beverage industry: trends and observations 2012. Beverage Industry Environmental Roundtable, AnteaGroup, St. Paul
- Bloemhof JM, Soysal M (2017) Sustainable food supply chain design. In: Bouchery Y, Corbett CJ, Fransoo J, Tan T (eds) Sustainable supply chains: a research-based textbook on operations and strategy. Springer, New York
- Boulay AM, Hoekstra AY, Vionnet S (2013) Complementarities of water-focused Life Cycle Assessment and Water Footprint Assessment. *Environ Sci Tech* 47(21):11926–11927
- Brauman KA, Siebert S, Foley JA (2013) Improvements in crop water productivity increase water sustainability and food security: A global analysis. *Environ Res Lett* 8(2):024030
- Cazcaro I, Duarte R, Sánchez Chóliz J (2013) Multiregional input-output model for the evaluation of Spanish water flows. *Environ Sci Tech* 47(21):12275–12283
- Chiu YW, Wu M (2012) Assessing county-level water footprints of different cellulosic-biofuel feedstock pathways. *Environ Sci Tech* 46:9155–9162
- Coca-Cola Europe (2011) Water footprint sustainability assessment: towards sustainable sugar sourcing in Europe, Brussels
- Daniels PL, Lenzen M, Kenway SJ (2011) The ins and outs of water use—a review of multi-region input-output analysis and water footprints for regional sustainability analysis and policy. *Econ Syst Res* 23(4):353–370
- Deloitte (2013) Moving beyond business as usual: a need for a step change in water risk management, CDP Global Water Report 2013, CDP, London
- Dominguez-Faus R, Powers SE, Burken JG, Alvarez PJ (2009) The water footprint of biofuels: a drink or drive issue? *Environ Sci Tech* 43(9):3005–3010
- Duarte R, Sánchez-Chóliz J, Bielsa J (2002) Water use in the Spanish economy: An input-output approach. *Ecol Econ* 43(1):71–85
- Ercin AE, Hoekstra AY (2014) Water footprint scenarios for 2050: A global analysis. *Environ Int* 64:71–82
- Ercin AE, Aldaya MM, Hoekstra AY (2011) Corporate water footprint accounting and impact assessment: The case of the water footprint of a sugar-containing carbonated beverage. *Water Resour Manag* 25(2):721–741
- Ewing BR, Hawkins TR, Wiedmann TO, Galli A, Ercin AE, Weinzettel J, Steen-Olsen K (2012) Integrating ecological and water footprint accounting in a multi-regional input-output framework. *Ecol Indic* 23:1–8
- FAO (2014) Aquastat database, food and agriculture organization of the United Nations, Rome, Italy. www.fao.org/nr/aquastat. Accessed 4 Aug 2014
- Feng K, Hubacek K, Minx J, Siu YL, Chapagain A, Yu Y, Guan D, Barrett J (2011a) Spatially explicit analysis of water footprints in the UK. *Water* 3(1):47–63
- Feng K, Chapagain A, Suh S, Pfister S, Hubacek K (2011b) Comparison of bottom-up and top-down approaches to calculating the water footprints of nations. *Econ Syst Res* 23(4):371–385
- Finnveden G, Hauschild MZ, Ekvall T, Guinée J, Heijungs R, Hellweg S, Koehler A, Pennington D, Suh S (2009) Recent developments in Life Cycle Assessment. *J Environ Manage* 91(1):1–21
- Franke NA, Boyacioglu H, Hoekstra AY (2013) Grey water footprint accounting: Tier 1 supporting guidelines. Value of Water Research Report Series No. 65, UNESCO-IHE, Delft
- Gerbens-Leenes W, Hoekstra AY (2011) The water footprint of biofuel-based transport. *Energy Environ Sci* 4(8):2658–2668
- Gerbens-Leenes PW, Hoekstra AY, Van der Meer T (2009a) The water footprint of energy from biomass: A quantitative assessment and consequences of an increasing share of bio-energy in energy supply. *Ecol Econ* 68(4):1052–1060

- Gerbens-Leenes W, Hoekstra AY, Van der Meer TH (2009b) The water footprint of bioenergy. *Proc Natl Acad Sci U S A* 106(25):10219–10223
- Gerbens-Leenes PW, Van Lienden AR, Hoekstra AY, Van der Meer TH (2012) Biofuel scenarios in a water perspective: The global blue and green water footprint of road transport in 2030. *Glob Environ Chang* 22:764–775
- Gerbens-Leenes PW, Xu L, De Vries GJ, Hoekstra AY (2014) The blue water footprint and land use of biofuels from algae. *Water Resour Res* 50(11):8549–8563
- Guinée J, Heijungs R (2017) Introduction to life cycle assessment. In: Bouchery Y, Corbett CJ, Fransoo J, Tan T (eds) *Sustainable supply chains: a research-based textbook on operations and strategy*. Springer, New York
- Hellweg S, Milà i Canals L (2014) Emerging approaches, challenges and opportunities in life cycle assessment. *Science* 344(6188):1109–1113
- Hoekstra AY (2013) *The water footprint of modern consumer society*. Routledge, London
- Hoekstra AY (2014a) Water scarcity challenges to business. *Nat Clim Chang* 4(5):318–320
- Hoekstra AY (2014b) Sustainable, efficient and equitable water use: The three pillars under wise freshwater allocation. *WIREs Water* 1(1):31–40
- Hoekstra AY (2015a) The water footprint of industry. In: Klemeš JJ (ed) *Assessing and measuring environmental impact and sustainability*. Butterworth-Heinemann, Oxford, pp 219–252
- Hoekstra AY (2015b) The sustainability of a single activity, production process or product. *Ecol Indic* 57:82–84
- Hoekstra AY, Mekonnen MM (2012) The water footprint of humanity. *Proc Natl Acad Sci* 109(9):3232–3237
- Hoekstra AY, Wiedmann TO (2014) Humanity’s unsustainable environmental footprint. *Science* 344(6188):1114–1117
- Hoekstra AY, Chapagain AK, Aldaya MM, Mekonnen MM (2011) *The water footprint assessment manual: Setting the global standard*. Earthscan, London
- Hoekstra AY, Mekonnen MM, Chapagain AK, Mathews RE, Richter BD (2012) Global monthly water scarcity: Blue water footprints versus blue water availability. *PLoS One* 7(2), e32688
- ISO (2014) *ISO 14046: Environmental Management—Water Footprint—Principles, Requirements and Guidelines*. International Organization for Standardization, Geneva
- Jefferies D, Muñoz I, Hodges J, King VJ, Aldaya M, Erchin AE, Milà i Canals L, Hoekstra AY (2012) Water footprint and life cycle assessment as approaches to assess potential impacts of products on water consumption: key learning points from pilot studies on tea and margarine. *J Clean Prod* 33:155–166
- King CW, Webber M (2008) Water intensity of transportation. *Environ Sci Tech* 42(21):7866–7872
- Kounina A, Margni M, Bayart J-B, Boulay A-M, Berger M, Bulle C, Frischknecht R, Koehler A, Milà I, Canals L, Motoshita M, Núñez M, Peters G, Pfister S, Ridoutt B, Van Zelm R, Verones F, Humbert S (2013) Review of methods addressing freshwater use in life cycle inventory and impact assessment. *Int J Life Cycle Assess* 18(3):707–721
- Lenzen M, Foran B (2001) An input-output analysis of Australian water usage. *Water Policy* 3(4):321–340
- Mekonnen MM, Hoekstra AY (2011) The green, blue and grey water footprint of crops and derived crop products. *Hydrol Earth Syst Sci* 15(5):1577–1600
- Mekonnen MM, Hoekstra AY (2012) A global assessment of the water footprint of farm animal products. *Ecosystems* 15(3):401–415
- Pfister S, Hellweg S (2009) The water “shoesize” vs. footprint of bioenergy. *Proc Natl Acad Sci* 106(35):E93–E94
- Rebitzer G, Ekvall T, Frischknecht R, Hunkeler D, Norris G, Rydberg T, Schmidt WP, Suh S, Weidema BP, Pennington DW (2004) *Life cycle assessment Part 1: Framework, goal and scope definition, inventory analysis, and applications*. *Environ Int* 30:701–720
- Ridoutt BG, Eady SJ, Sellahewa J, Simons L, Bektash R (2009) Water footprinting at the product brand level: case study and future challenges. *J Clean Prod* 17:1228–1235
- Ruini L, Marino M, Pignatelli S, Laio F, Ridolfi L (2013) Water footprint of a large-sized food company: The case of Barilla pasta production. *Water Res Ind* 1–2:7–24

- SABMiller and WWF-UK (2009) Water footprinting: identifying & addressing water risks in the value chain, SABMiller, Woking, UK/WWF-UK, Godalming
- SABMiller, GTZ and WWF (2010) Water futures: working together for a secure water future, SABMiller, Woking, UK/WWF-UK, Godalming
- Sarni W (2011) Corporate water strategies. Earthscan, London
- Sikirica N (2011) Water footprint assessment bananas and pineapples. Dole Food Company, Soil & More International, Driebergen
- Steen-Olsen K, Weinzettel J, Cranston G, Ercin AE, Hertwich EG (2012) Carbon, land, and water footprint accounts for the European Union: Consumption, production, and displacements through international trade. *Environ Sci Tech* 46(20):10883–10891
- TCCC and TNC (2010) Product water footprint assessments: practical application in corporate water stewardship, The Coca-Cola Company, Atlanta, USA/The Nature Conservancy, Arlington
- UN (2008) International standard industrial classification of all economic activities, Revision 4. Statistics Division, Department of Economic and Social Affairs, United Nations, New York
- WEF (2014) Global risks 2014. World Economic Forum, Geneva
- Yu Y, Hubacek K, Feng K, Guan D (2010) Assessing regional and global water footprints for the UK. *Ecol Econ* 69(5):1140–1147
- Zhang C, Anadon LD (2014) A multi-regional input-output analysis of domestic virtual water trade and provincial water footprint in China. *Ecol Econ* 100:159–172
- Zhang Z, Shi M, Yang H, Chapagain A (2011) An input-output analysis of trends in virtual water trade and the impact on water resources and uses in China. *Econ Syst Res* 23(4):431–446
- Zhao X, Chen B, Yang ZF (2009) National water footprint in an input-output framework-A case study of China 2002. *Ecol Model* 220(2):245–253