The Water Footprint: The Relation Between Human Consumption and Water Use

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Abstract It is increasingly recognised that freshwater scarcity and pollution are to be understood in a global context. Local water depletion and pollution are often closely tied to the structure of the global economy. With increasing trade between nations and continents, water is more frequently used to produce export goods. International trade in commodities implies long-distance transfers of water in virtual form, where virtual water is understood as the volume of water that has been used to produce a commodity and that is thus virtually embedded in it. Knowledge about the virtual water flows entering and leaving a country can cast a completely new light on the actual water scarcity of a country. At the same time, it becomes increasingly relevant to consider the linkages between consumer goods and impacts on freshwater systems. This can improve our understanding of the processes that drive changes imposed on freshwater systems and help to develop policies of wise water governance. The water footprint is an innovative concept to analyse water consumption and pollution along supply chains, assess the sustainability of water use and explore where and how water use can best be reduced. This chapter shows how the water footprint concept can be used to understand the international dimension of water and to assess water use behind daily consumer goods. This chapter argues for greater product transparency, water footprint ceilings per river basin and water footprint benchmarks for water-intensive commodities.

1 Introduction

The desirability of reducing our carbon footprint is generally recognised, but the related and equally urgent need to reduce our water footprint is often overlooked. Recent research has shown that about 4 % of the water footprint of humanity relates to water use at home (Hoekstra and Mekonnen 2012). This means that if people

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consider reducing their water footprint, they better critically look at their indirect water footprint than at their water use in the kitchen, bathroom and garden. Wasting water never makes sense, so saving water at home when possible is certainly advisable, but when we would limit our actions to water reductions at home, many of the most severe water problems in the world would hardly be lessened. The water in the Murray-Darling basin in Australia is so scarce mostly because of water use in irrigated agriculture (Pittock and Connell 2010). The Ogallala Aquifer in the American Midwest is gradually being depleted because of water abstractions for the irrigation of crops such as maize and wheat (McGuire 2007). In Italy, groundwater reservoirs in the south are overexploited, among others for growing durum wheat for making pasta (Aldaya and Hoekstra 2010).

In this chapter, I will first introduce the water footprint concept, an indicator increasingly used worldwide to assess the implications of consumption and trade on water resource use and pollution. Next, I will report on the water footprint of Italian consumption. Subsequently, I will zoom in on an important component in the water footprint of humanity: the hidden water resource use behind meat and dairy. I will compare the water footprint of animal products with the water footprint of crops and the water footprint of a meat-based diet with the water footprint of a vegetarian diet. I will then show that understanding the relation between food consumption and the use of freshwater resources is no longer just a local issue. Water has become a global resource, whereby—due to international trade—food consumption in one place often affects the water demand in another place. Finally, an argument is made for product transparency, which would allow us to better link individual products to associated water impacts, which in turn can drive efforts to reduce those impacts.

2 The Water Footprint Concept

The water footprint concept is an indicator of water use in relation to consumer goods (Hoekstra et al. 2011). The concept is an analogue to the ecological and the carbon footprint, but indicates water use instead of land or fossil energy use. The water footprint of a product is the volume of freshwater used to produce the product, measured over the various steps of the production chain. Water use is measured in terms of water volumes consumed or polluted. Water consumption refers to water evaporated or incorporated into a product. The water footprint is a geographically explicit indicator that shows volumes of water use and pollution, but also the locations. A water footprint generally breaks down into three components: the blue, green and grey water footprint. The blue water footprint is the volume of freshwater that is evaporated from the global blue water resources (surface and ground water). The green water footprint is the volume of water evaporated from the global green water resources (rainwater stored in the soil). The grey water footprint is the volume of polluted water, which is quantified as the volume of water that is required to dilute pollutants to such an extent that the quality of the ambient water remains above agreed water quality standards (Hoekstra and Chapagain

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2008). In order to make sure that scientifically robust methods are applied and to ensure that a fair comparison can be made between different water footprint studies, the Water Footprint Network with its partners has developed the Global Water Footprint Standard, which was launched in February 2011 (Hoekstra et al. 2011). The figures presented in this paper are based on this standard. The Global Water Footprint Standard covers a comprehensive set of definitions and methods for water footprint accounting. It shows how green, blue and grey water footprints are calculated for individual processes and products, as well as for consumers, nations and businesses. It also includes methods for water footprint sustainability assessment and a library of water footprint response options.

3 The Water Footprint of Italian Consumption

On average, the water footprint of Italian consumption is 6300 L per day per person, which is 1.65 times larger than the global average. Only 4 % of the water footprint of Italian consumption is related to water use at home, which is in line with the global picture. About 96 % of the water footprint of consumption is thus 'invisible' for the consumer: it relates to the water consumption and pollution behind the products that consumers buy in the supermarket or elsewhere. About 89 % of the Italian water footprint relates to consumption of agricultural products and 7 % to industrial products. Nearly, half of the water footprint of Italian consumption is related to the consumption of animal products (Fig. 1).

About 60 % of the water footprint of Italian consumption lies outside the country. Figures 2, 3, 4 and 5 map the green, blue, grey and total water footprint of Italian consumption in the world. The largest fractions of the external water footprint of Italian consumption lie in France (harbouring about 9 % of Italy's external water footprint, mostly for production of animal products and wheat), Brazil (7 %, mostly animal products, soya bean, coffee), Germany (6 %, mostly animal products), Tunisia (6 %, mostly olives and cotton) and Spain (6 %, mostly olives). Next in row are the following countries: the USA (wheat, soya bean, animal products), Argentina (soya bean), India (cotton and coffee), the Russian Federation (wheat, animal products, sunflower seed, industrial products), the Netherlands (animal products), Romania (cotton, animal products, industrial products) and China (cotton and industrial products).

4 The Water Footprint of Animal Products

Much of the grains cultivated in the world are not for human consumption but for animals. In the period 2001–2007, on average 37 % of the cereals produced in the world were used for animal feed (FAO 2011). Surprisingly, however, there is little attention among scientists or policy makers to the relation between water use and

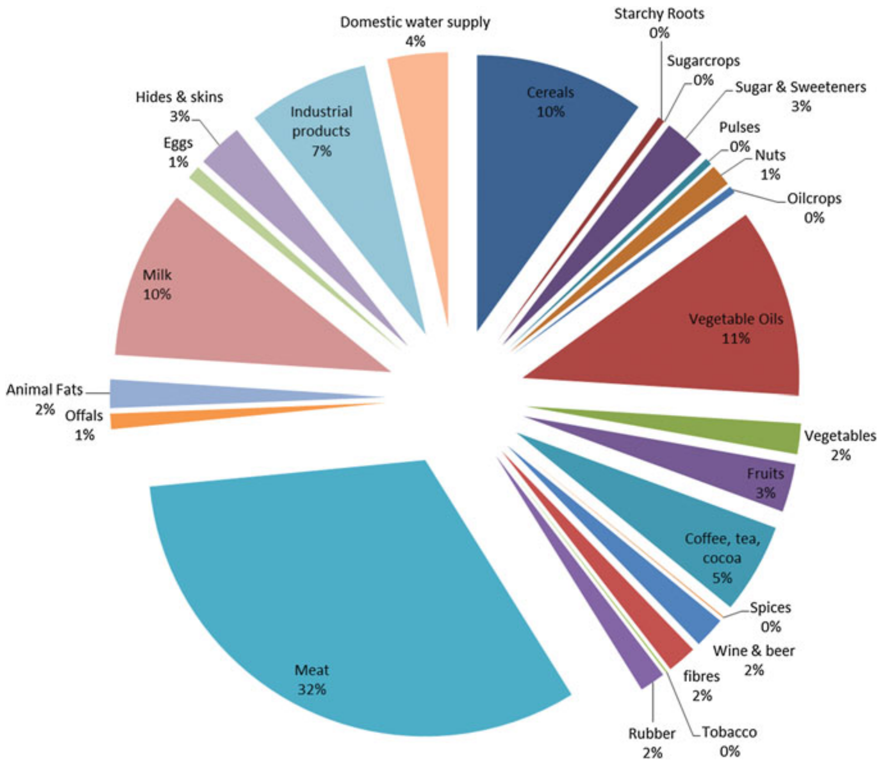

Fig. 1 The composition of the water footprint of the average Italian consumer. Period 1996–2005. *Data source* Mekonnen and Hoekstra (2011)

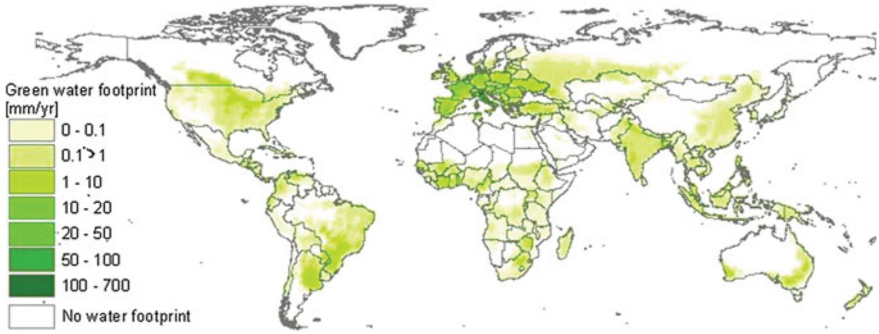

Fig. 2 The global green water footprint of Italian consumption. Period 1996–2005. *Source* Mekonnen and Hoekstra (2011)

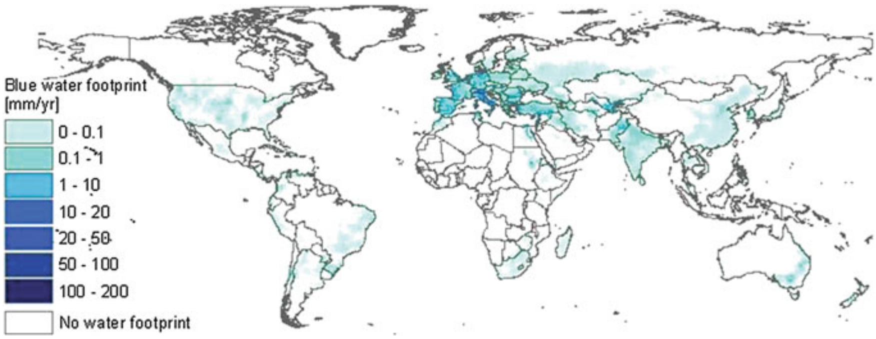

Fig. 3 The global blue water footprint of Italian consumption. Period 1996–2005. *Source* Mekonnen and Hoekstra (2011)

Fig. 4 The global grey water footprint of Italian consumption. Period 1996–2005. *Source* Mekonnen and Hoekstra (2011)

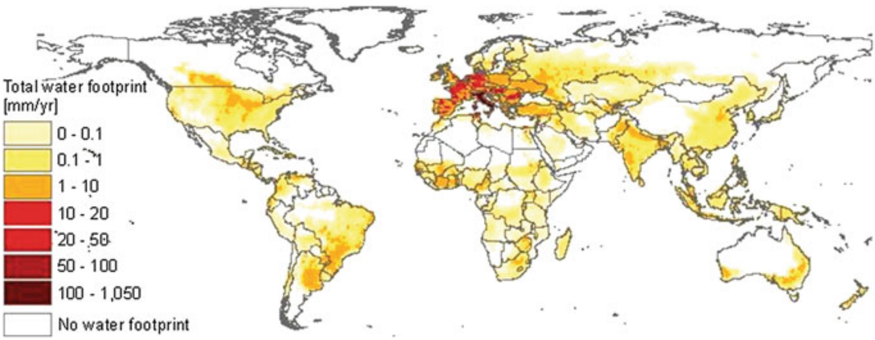

Fig. 5 The aggregated (green + blue + grey) water footprint of Italian consumption. Period 1996–2005. *Source* Mekonnen and Hoekstra (2011)

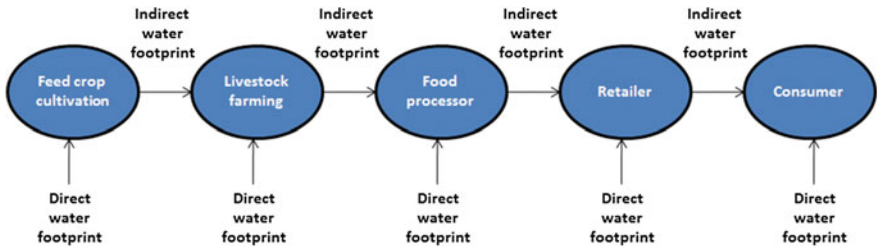

Fig. 6 The direct and indirect water footprint in each stage of the supply chain of an animal product. *Source* Hoekstra (2013)

the consumption of meat and dairy. It becomes increasingly relevant to study the implications of farm animals on water resource use, not only because the global meat production has almost doubled in the period 1980–2004 (FAO 2005), but also because of the projected doubling of meat production in the period 2000–2050 (Steinfeld et al. 2006).

The supply chain of an animal product starts with feed crop cultivation and ends with the consumer (Fig. 6). In each step of the chain, there is a direct water footprint, which refers to the water consumption or pollution in that step, but also an indirect water footprint, which refers to the water consumption or pollution in the previous steps. By far, the biggest contribution to the total water footprint of all final animal products comes from the first step: growing the feed. This step is the farthest removed from the consumer, which explains why consumers generally have little notion about the fact that animal products require a lot of land and water (Naylor et al. 2005). Besides, the feed will often be grown in areas completely different from where the consumption of the final product takes place.

In order to better understand the water footprint of an animal product, we better start with the water footprint of feed crops. The combined green–blue water footprint of a crop (in m^3/ton) when harvested from the field is equal to the total evapotranspiration from the crop field during the growing period (m^3/ha) divided by the crop yield (ton/ha). The crop water use depends on the crop water requirement on the one hand and the actual soil water available on the other hand. Soil water is replenished either naturally through rainwater or artificially through irrigation water. The crop water requirement is the total water needed for evapotranspiration under ideal growth conditions, measured from planting to harvest. It obviously depends on the type of crop and climate. Actual water use by the crop is equal to the crop water requirement if rainwater is sufficient or if shortages are supplemented through irrigation. In the case of rainwater deficiency and the absence of irrigation, actual crop water use is equal to effective rainfall. The green water footprint refers to the part of the crop water requirement met through rainfall; the blue water footprint is the part of the crop water requirement met through irrigation. The grey water footprint is calculated as the load of a pollutant (fertiliser, pesticide) that leaches from the field to the groundwater or runs off to the surface water divided by the difference between the maximum allowable and natural concentration for the pollutant in the water body.

The water footprint of an animal at the end of its lifetime can be calculated based on the water footprint of all feed consumed during its lifetime and the volumes of water consumed for drinking and for example cleaning the stables. One will have to know the age of the animal when slaughtered and the diet of the animal during its various stages of life. The water footprint of the animal as a whole is allocated to the different products that are derived from the animal. This allocation is done on the basis of the relative values of the various animal products, as can be calculated from the market prices of the different products. The allocation is done such that there is no double counting and that the largest shares of the total water input are assigned to the high-value products and smaller shares to the low-value products.

About 98 % of the water footprint of animal products relates to water use for feed (Mekonnen and Hoekstra 2012). A recent study by Gerbens-Leenes et al. (2011) shows that there are two major determining factors for the water footprint of animal products. The first factor is the feed conversion efficiency, which measures the amount of feed to produce a given amount of meat, eggs or milk. As animals are generally able to move more and take longer to reach slaughter weight in grazing systems, they consume a greater proportion of food to convert to meat. Due to this, the feed conversion efficiency improves from grazing systems through mixed systems to industrial systems and leads to a smaller water footprint in industrial systems. The second factor is the composition of the feed eaten by the animals in each system and works precisely in the other direction, in favour of grazing systems. When the amount of feed concentrates increases, the water footprint will increase as well, because feed concentrates have a relatively large water footprint, while roughages (grass, crop residues and fodder crops) have a relatively small water footprint. The increasing fraction of animal feed concentrates and decreasing fraction of roughages from grazing through mixed to industrial systems (Hendy et al. 1995) result in a smaller water footprint in grazing and mixed systems compared to industrial systems. In general, the water footprint of concentrates is five times larger than the water footprint of roughages. While the total mixture of roughages has a water footprint of around 200 m^3/tonne (global average), this is about 1000 m^3/tonne for the package of ingredients contained in concentrates. As roughages are mainly rain fed and crops for concentrates are often irrigated and fertilised, the blue and grey water footprint of concentrates are even 43 and 61 times that of roughages, respectively.

If we take beef as an example, it is clear from the above that the water footprint will strongly vary depending on the production region, feed composition and origin of the feed ingredients. The water footprint of beef from an industrial system may partly refer to irrigation water (blue water) to grow feed in an area remote from where the cow is raised. This can be an area where water is abundantly available, but it may also be an area where water is scarce and where minimum environmental flow requirements are not met due to overdraft. The water footprint of beef from a grazing system will mostly refer to green water used in nearby pastures. If the pastures used are either dry- or wetlands that cannot be used for crop cultivation, the green water flow turned into meat could not have been used to produce food crops instead. If, however, the pastures can be substituted by cropland, the green water allocated to meat production is no longer available for food crop production. This explains why the water footprint is to be seen as a multidimensional indicator. One should not only look at the total water footprint as a volumetric value, but also consider the green, blue and grey components separately and look at where each of the water footprint components is located. The social and ecological impacts of water use at a certain location depend on the scarcity and alternative uses of water at that location.

5 The Water Footprint of Animal Products Versus Crop Products

Mekonnen and Hoekstra (2012) have shown that the water footprint of any animal product is larger than the water footprint of a wisely chosen crop product with equivalent nutritional value. Ercin et al. (2011) illustrate this by comparing the water footprint of two soya products with two equivalent animal products. They calculate that 1 L of soya milk produced in Belgium has a water footprint of about 300 L, whereas the water footprint of 1 L of cow's milk is more than three times bigger. The water footprint of a 150-g soya burger produced in the Netherlands appears to be about 160 L, while the water footprint of an average 150-g beef burger is nearly fifteen times bigger. Table 1 shows the global average water footprint of a number of crop and animal products. The numbers show that the average water footprint per calorie for beef is twenty times larger than for cereals and starchy roots. The water footprint per gram of protein for milk, eggs and chicken meat is about 1.5 times larger than for pulses. For beef, the water footprint per gram of protein is 6 times larger than for pulses. Butter has a relatively small water footprint per gram of fat, even lower than for oil crops, but all other animal products have larger water footprints per gram of fat when compared to oil crops.

The global water footprint of animal production amounts to 2422 billion m^3 per year (87 % green, 6 % blue, 7 % grey). One-third of this total is related to beef cattle, another 19 % to dairy cattle (Mekonnen and Hoekstra 2012). The largest fraction (98 %) of the water footprint of animal products refers to the water footprint of the feed for the animals. Drinking water for the animals, service water and feed mixing water accounts for 1.1, 0.8 and 0.03 %, respectively.

6 The Water Footprint of a Meat Versus Vegetarian Diet

Dietary habits greatly influence the overall water footprint of people. In industrialised countries, the average calorie consumption is about 3400 kcal per day (FAO 2011), roughly 30 % of that comes from animal products. When we assume

Table 1 The global average water footprint of crop and animal products

Food item	Water footprint per unit of weight (L/kg)				Nutritional content			Water footprint per unit of nutritional value		
	Green	Blue	Grey	Total	Calorie (kcal/kg)	Protein (g/kg)	Fat (g/kg)	Calorie (L/kcal)	Protein (L/g protein)	Fat (L/g fat)
Sugar crops	130	52	15	197	285	0.0	0.0	0.69	0.0	0.0
Vegetables	194	43	85	322	240	12	2.1	1.34	26	154
Starchy roots	327	16	43	387	827	13	1.7	0.47	31	226
Fruits	726	147	89	962	460	5.3	2.8	2.09	180	348
Cereals	1232	228	184	1644	3208	80	15	0.51	21	112
Oil crops	2023	220	121	2364	2908	146	209	0.81	16	11
Pulses	3180	141	734	4055	3412	215	23	1.19	19	180
Nuts	7016	1367	680	9063	2500	65	193	3.63	139	47
Milk	863	86	72	1020	560	33	31	1.82	31	33
Eggs	2592	244	429	3265	1425	111	100	2.29	29	33
Chicken meat	3545	313	467	4325	1440	127	100	3.00	34	43
Butter	4695	465	393	5553	7692	0.0	872	0.72	0.0	6.4
Pig meat	4907	459	622	5988	2786	105	259	2.15	57	23
Sheep/goat meat	8253	457	53	8763	2059	139	163	4.25	63	54
Bovine meat	14414	550	451	15415	1513	138	101	10.19	112	153

Source Mekonnen and Hoekstra (2012)

Table 2 The water footprint of two different diets in industrialised countries

	Meat diet			Vegetarian diet		
	kcal/day	litre/kcal	litre/day	kcal/day	litre/kcal	litre/day
Animal origin	950	2.5	2375	300	2.5	750
Vegetable origin	2450	0.5	1225	3100	0.5	1550
Total	3400		3600	3400		2300

Source Hoekstra (2012)

that the average daily portion of animal products is a reasonable mix of beef, pork, poultry, fish, eggs and dairy products, we can estimate that 1 kcal of animal product requires roughly 2.5 L of water on average. Products from vegetable origin, on the other hand, require roughly 0.5 L of water per kcal, this time assuming a reasonable mix of cereals, pulses, roots, fruit and vegetables. Under these circumstances, producing the food for one day takes 3600 L of water (Table 2). For the vegetarian diet, we assume that a smaller fraction is of animal origin (not zero, because of the dairy products still consumed), but keep all other factors equal. This reduces the food-related water footprint to 2300 L/day, which means a reduction of 36 %. Keeping in mind that for the 'meat eater', we had taken the average diet of a whole population and that meat consumption varies within a population; larger water savings can be achieved by individuals that eat more meat than the average person.

From the above figures, it is obvious that consumers can reduce their water footprint through reducing the volume of their meat consumption. Alternatively, however, or in addition, consumers can reduce their water footprint by being more selective in the choice of which piece of meat they pick. Chickens are less water intensive than cows and beef from one production system cannot be compared in terms of associated water impacts to beef from another production system. Grazing livestock depends on local rain, while factory-farm livestock often relates to blue water consumption and pollution elsewhere.

7 The Local and Global Dimensions of Water Governance

Problems of water scarcity and pollution always become manifest locally and during specific parts of the year. However, research on the relation between consumption, trade and water resource use during the past decade has made clear that protection of freshwater resources can no longer be regarded as just an issue for individual countries or river basins. Although in many countries most of the food still originates from the country itself, substantial volumes of food, feed and animal products are internationally traded. As a result, all countries import and export water in virtual form, i.e. in the form of agricultural commodities (Hoekstra and Chapagain 2008; Allan 2011). Total international virtual water flows related to global trade in animal products add up to 272 billion m^3/year, a volume equivalent to about half the annual Mississippi run-off (Mekonnen and Hoekstra 2011).

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Not only livestock and livestock products are internationally traded, also feed crops are traded (Galloway et al. 2007). In trade statistics, however, it is difficult to distinguish between food and feed crops, because they are mostly the same crops, only the application is different. Worldwide, trade in crops and crop products results in international virtual water flows that add up to 1766 billion m^3/year (Mekonnen and Hoekstra 2011).

Until today, water is still mostly regarded as a local or regional resource, to be managed preferably at catchment or river basin level. However, this approach obscures the fact that many water problems are related to remote consumption elsewhere. Water problems are an intrinsic part of the world's economic structure in which water scarcity is not translated into costs to either producers or consumers; as a result, there are many places where water resources are depleted or polluted, with producers and consumers along the supply chain benefiting at the cost of local communities and ecosystems. It is unlikely that consumption and trade are sustainable if they are accompanied by water depletion or pollution somewhere along the supply chain. Typical products that can often be associated with remote water depletion and pollution are cotton and sugar products. For animal products, it is much more difficult to tell whether they relate to such problems, because animals are often fed with a variety of feed ingredients and feed supply chains are difficult to trace. So unless we have milk, cheese, eggs or meat from an animal that was raised locally and that grazed locally or was otherwise fed with locally grown stuff, it is hard to say something about which claim such product has put on the world's scarce freshwater resources. The increasing complexity of our food system in general and the animal product system in particular hides the existing links between the food we buy and the resource use and associated impacts that underlie it.

8 Product Transparency

In order to know what we eat, we will need a form of product transparency that is currently completely lacking. It is reasonable that consumers (or consumer organisations on their behalf) have access to information about the history of a product. A relevant question is: How water intensive is a particular product that is for sale and to which extent does it relate to water depletion and/or pollution? Establishing a mechanism that makes sure that such information is available is not an easy task. It requires a form of accounting along production and supply chains that accumulates relevant information all the way to the end point of a chain.

Governments that put interest in 'sustainable consumption' should translate this interest into their trade policy. The European Union, given the fact that about 40 % of the total water footprint of the EU citizens lies outside its own territory (Mekonnen and Hoekstra 2011), may strive towards more transparency about the water impacts of imported products. Achieving such a goal will obviously be much easier if there is international cooperation in this field. In cases where industrialised countries import feed from developing countries, the former can support the latter within the context of development cooperation policy in reducing the impacts on local water systems by helping to set up better systems of water governance.

Business can have a key role as well, particularly the large food processors and retailers. Since they form an intermediary between farmers and consumers, they are the ones that have to pass on key information about the products that they are trading. As big customers, they can also put pressure on and support farmers to actually reduce their water footprint and require them to provide proper environmental accounts. If it comes to water accounting, there are currently several parallel processes going on in the business world. First of all, there is an increasing interest in the water use in supply chains, on top of the traditional interest in their own operational water use. Second, several companies, including for instance Unilever and The Coca Cola Company, have started to explore how water footprint accounting can be practically implemented. Some businesses think about extending their annual environmental report with a paragraph on the water footprint of their business. Others speak about water labelling of products (either on the product itself or through information available online), and yet others explore the idea of water certification for companies. The interest in water footprint accounting comes from various business sectors, ranging from the food and beverage industry to the apparel and paper industry.

9 Conclusion

The interest in the water footprint in the food sector is growing rapidly, but most interest thus far comes from the beverage sector (Sarni 2011). Besides, most companies still restrict their interest in water to their own operational water footprint, leaving the supply chain water footprint out of scope. Little interest in water has been shown in the meat and dairy sectors, which is surprising given the fact that the meat and dairy sectors contribute more than a quarter to the global water footprint of humanity. Also from the governmental side, there is hardly any attention to the relation between animal products and water resources. There does not exist a national water plan in the world that addresses the issue that meat and dairy are among the most water-intensive consumer products, let alone that national water policies somehow involve consumers or the meat and dairy industry in this respect. Water policies are often focussed at 'sustainable production', but they seldom address 'sustainable consumption'. They address the issue of water-use efficiency within agriculture (more crop per drop), but hardly ever the issue of water-use efficiency in the food system as a whole (more kcal per drop). The advantage of involving the whole supply chain is that enormous leverage can be created to establish change.

The issue of wise water governance is a shared responsibility of consumers, governments, businesses and investors. Each of those players has a different role. Consumers should demand transparency about the water consumption and pollution underlying consumer products from business and governments, so that one is better informed about associated water resource use and impacts. Consumers can choose to consume less animal products or choose, whenever proper information allows, for products with a water footprint that meets a certain benchmark. National governments can—preferably in the context of an international agreement—put regulations in place that urge businesses along the supply chain to cooperate in creating product transparency. Governments can also tune their trade and development cooperation policies towards their wish to promote consumption of and trade in sustainable products. Governments should further play a leading role in establishing water footprint ceilings per river basin, to ensure that in each river basin, the water footprint does not exceed available water resources. Companies, particularly big food processors and retailers, can use their power in the supply chain to effectuate product transparency. They can also cooperate in water labelling, certification and benchmarking schemes and produce annual water accounts that include a report of the supply chain water footprints and associated impacts of their products. Investors, finally, can be an important driving force to encourage companies to put water risk and good water stewardship higher on their corporate agenda. Some steps in creating product transparency in the food sector have been made to address concerns of product quality and public health. It is likely that in the future, there will be increasing interest in transparency regarding environmental issues like water resource use as well.

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