Ecological Economics 69 (2009) 82–92

Contents lists available at ScienceDirect

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolecon

Analysis

The external water footprint of the Netherlands: Geographically-explicit quantification and impact assessment

P.R. van Oel *, M.M. Mekonnen, A.Y. Hoekstra

Dept. of Water Engineering and Management, University of Twente, Enschede, The Netherlands

ARTICLE INFO

Article history:
Received 18 February 2009
Received in revised form 19 June 2009
Accepted 15 July 2009
Available online 3 September 2009

Keywords:
Virtual-water
External water footprint
Water scarcity
Netherlands

ABSTRACT

This study quantifies the external water footprint of the Netherlands by partner country and import product and assesses the impact of this footprint by contrasting the geographically-explicit water footprint with water scarcity in the different parts of the world. The total water footprint of the Netherlands is estimated to be about 2300 m^3/year/cap, of which 67% relates to the consumption of agricultural goods, 31% to the consumption of industrial goods, and 2% to domestic water use. The Dutch water footprint related to the consumption of agricultural goods, is composed as follows: 46% related to livestock products; 17% oil crops and oil from oil crops; 12% coffee, tea, cocoa and tobacco; 8% cereals and beer; 6% cotton products; 5% fruits; and 6% other agricultural products. About 11% of the water footprint of the Netherlands is internal and 89% is external. Only 44% of virtual-water import relates to products consumed in the Netherlands, thus constituting the external water footprint. For agricultural products this is 40% and for industrial products this is 60%. The remaining 56% of the virtual-water import to the Netherlands is re-exported. The impact of the external water footprint of Dutch consumers is highest in countries that experience serious water scarcity. Based on indicators for water scarcity the following eight countries have been identified as most seriously affected: China; India; Spain; Turkey; Pakistan; Sudan; South Africa; and Mexico. This study shows that Dutch consumption implies the use of water resources throughout the world, with significant impacts in water-scarce regions.

1. Introduction

The background of this study is the recognition that there is a relation between consumption by Dutch consumers and impacts on water systems elsewhere in the world. Many of the goods consumed in the Netherlands are not produced in the Netherlands, but abroad. Some goods, most in particular agriculture-based products, require a lot of water during production. These water-intensive production processes are accompanied by impacts on the water systems at the various locations where the production processes take place. The impacts vary from reduced river water flows, declined lake levels and declined ground water tables to increased salt intrusion in coastal areas and pollution of freshwater bodies. As an indicator of the water use related to consumption we use the water footprint concept. The water footprint of a nation is defined as the total amount of freshwater that is used to produce the goods and services consumed by the inhabitants of the nation (Hoekstra and Chapagain, 2007a, 2008). The total water footprint of a country includes two components: the part of the footprint that falls inside the country (internal water footprint) and the part of the footprint that presses on other countries in the world (external water footprint). In this study, we focus on the external water footprint of the Netherlands.

The external water footprint of the Netherlands is the volume of water used in other countries to produce goods and services imported and consumed by the inhabitants of the Netherlands. The water footprint is a quantitative measure of the amount of water consumed. It breaks down into three components: the blue, green and grey water footprint. The blue water footprint is the volume of freshwater that evaporated from the global blue water resources (surface water and ground water) to produce the goods and services consumed by the people in a nation. The green water footprint is the volume of water evaporated from the global green water resources (rainwater stored in the soil as soil moisture). The grey water footprint is the volume of polluted water that associates with the production of all goods consumed in the nation. The latter is calculated as the volume of water that is required to dilute pollutants to such an extent that the quality of the water remains above agreed water quality standards. Analysis of the grey water footprint of the Dutch community will be done in this study only in the last phase, when analyzing the impacts at hotspots.

The external water footprint of the Netherlands is specified according to (i) partner countries and (ii) imported products. The results of the country and product analyses are confronted with

* Corresponding author. Water Engineering and Management, Faculty of Engineering Technology, University of Twente, P.O. Box 217, 7500 AE Enschede, The Netherlands. Tel.: +31 53 4893911; fax; +31 53 4895377.
E-mail address: p.r.vanoel@utwente.nl (P.R. van Oel).

0921-8009/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.ecolecon.2009.07.014

water-scarcity indicators. In this way, hotspots are identified where the external water footprint of the Netherlands expectedly has the largest impacts. For a number of selected hotspots the impact on the affected local water systems will be further analyzed. The research is driven by the following research questions: What is the water use outside of the Dutch borders in effect of Dutch consumption? In which countries is the external footprint concentrated? What are the main products related to this external footprint? What is the external water footprint related to total water use behind imports into the Netherlands? In which countries is the impact of the external water footprint most serious (hotspots)? What are the impacts of the external water footprint on local water systems in the identified hotspots?

We have considered the period 1996–2005, which is long enough to get a good impression of average Dutch trade and its effects on the Dutch water footprint, excluding the effects of deviations in specific years, but which is not long enough to carry out trend-analyses, which was out of the scope of the current study. In quantifying the total external water footprint of the Netherlands it was not feasible to distinguish between the green, blue and grey components of the water footprint, but in the analysis of the identified hotspots, a specification of the green, blue and grey water footprint was made.

2. Methods

As defined by Hoekstra and Chapagain (2007a, 2008), the water footprint (WF) of Dutch consumers has two components: the internal water footprint (WF_i) and the external water footprint (WF_e):

$$WF[NL] = WF_i[NL] + WF_e[NL] \tag{1}$$

The internal water footprint is defined as the annual use of domestic water sources to produce goods and services consumed by the Dutch population. It is the sum of the total water volume used from the domestic water resources in the national economy (WU) minus the volume of virtual-water export to other countries insofar as related to the export of products produced with national water resources ($V_{e,d}$):

$$WF_i[NL] = WU[NL] - V_{e,d}[NL] \tag{2}$$

The external water footprint is defined as the annual volume of freshwater resources used in other countries to produce goods and services consumed by the population of these countries. It is equal to the virtual-water import into the country (V_i) minus the volume of virtual-water exported to other countries as a result of re-export of imported products ($V_{e,r}$):

$$WF_e[NL] = V_i[NL] - V_{e,r}[NL] \tag{3}$$

As Fig. 1 shows, the virtual-water export (V_e) consists of exported water of domestic origin ($V_{e,d}$) and re-exported water of foreign origin ($V_{e,r}$):

$$V_e[NL] = V_{e,d}[NL] + V_{e,r}[NL] \tag{4}$$

The virtual-water import will partly be consumed, thus constituting the external water footprint of the country (WF_e), and partly be re-exported ($V_{e,r}$):

$$V_i[NL] = WF_e[NL] + V_{e,r}[NL] \tag{5}$$

Finally, we see in Fig. 1 that the sum of V_i and WU is equal to the sum of V_e and WF. We call this sum the virtual-water budget (V_b) of a country (Ma et al., 2006; Hoekstra and Chapagain, 2008).

$$\begin{aligned} V_b[NL] &= V_i[NL] + WU[NL] \\ &= V_e[NL] + WF[NL] \end{aligned} \tag{6}$$

The water footprint (WF) of a country can be estimated through a bottom-up or top-down approach. In this study both approaches are applied in order to be able to compare the outcomes. As will become clear, however, the bottom-up approach gives more reliable results in the case of the Netherlands, so that in the rest of the study, after the comparison of the outcomes of both approaches, we will work with the outcomes of the bottom-up approach.

2.1. Bottom-up approach

In the bottom-up approach, the water footprint (WF) of the Netherlands (NL) is calculated by adding the direct water use by people and their indirect water use:

$$WF[NL] = WF_{\text{direct}}[NL] + WF_{\text{indirect}}[NL] \tag{7}$$

The direct water use refers to the water that people consume at home. The indirect water use of people refers to the water use by others to make the goods and services consumed. It refers to the water that was used to produce for example the food, clothes, paper, energy and industrial goods consumed. The indirect water use is calculated by multiplying all goods and services consumed by the inhabitants of the Netherlands by the respective water needs for those goods and services:

$$WF_{\text{indirect}}[NL, p] = \sum_{p=1}^{n} (Cons[NL, p] \cdot vwc^*[NL, p]) \tag{8}$$

$Cons[NL,p]$ is Dutch consumption of product p (unit/year) and $vwc^*[NL,p]$ the virtual-water content of this product (m^3/unit). The set of products considered refers to the full range of final consumer goods and services. The virtual-water content of a product is the volume of freshwater used to produce the product, measured at the place where the product was actually produced. The virtual-water content of a product thus varies as a function of place and conditions of production. It refers to the sum of the water use in the various steps of the production chain. The adjective 'virtual' refers to the fact that most of the water used to produce a product is not contained in the product. The real-water content of products is generally negligible if compared to the virtual-water content. The virtual-water content of individual primary and processed products is calculated (per country) based on the method described in Hoekstra and Chapagain (2008).

In the case of agricultural products, the virtual-water content is expressed in terms of m^3/ton and consumption is expressed in ton/year. In the case of industrial products, the virtual-water content is, for practical reasons, expressed in terms of m^3/US$ instead of m^3/ton. Industrial products show a relatively high heterogeneity and there are often different production methods for one type of product. As a result, the weight of an industrial product is not an as obvious indicator of underlying water use as in the case of an agricultural product. Since industrial production in a sector as a whole is generally expressed in monetary terms, it is easiest to consider water use in a sector per monetary unit as well.

The total volume of a product (p) consumed in a country will generally originate from different countries (c). The average virtual-water content of a product consumed in the Netherlands is estimated by assuming that:

$$vwc^*[NL, p] = \frac{Prod[NL, p] \cdot vwc[NL, p] + \sum_{c=1}^{m} (I[c, p] \cdot vwc[c, p])}{Prod[NL, p] + \sum_{c=1}^{m} I[c, p]} \tag{9}$$

The assumption here is that consumption originates from domestic production ($Prod$, tons/year) and imports (I, tons/year) according to their relative volumes.

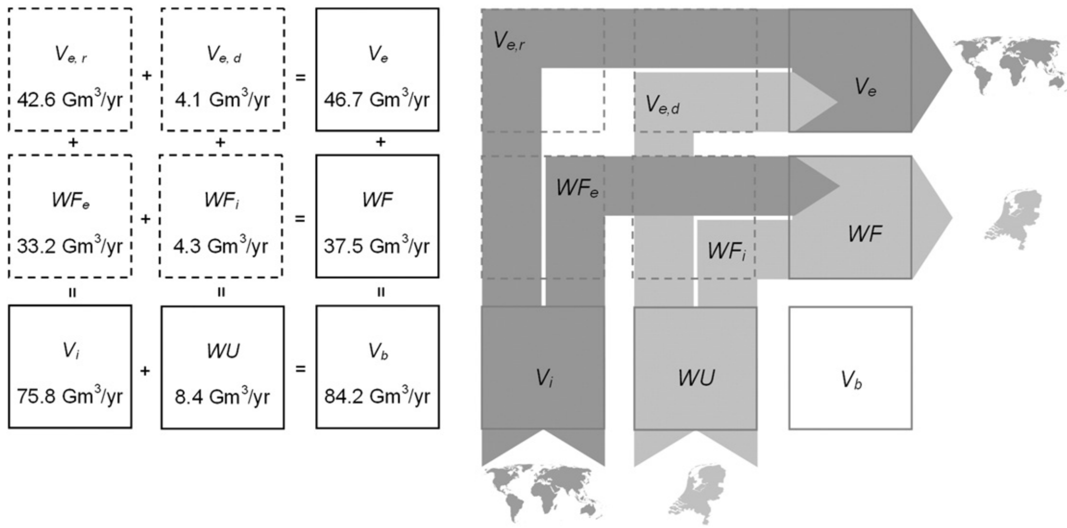

Fig. 1. The relation between virtual-water import (V_i), virtual-water export (V_e), use of national water resources (*WU*) and the water footprint (*WF*) of a country. The numbers in the boxes are average values for 4 the Netherlands for the period 1996–2005.

2.2. Top-down approach

Another way of assessing the water footprint of a country (*WF*, m^3/year) is the top-down approach, which takes the total water use (*WU*) in the country as starting point and then adds the incoming virtual-water flow (V_i) and subtracts the virtual-water export (V_e):

$$WF[NL] = WU[NL] + V_i[NL] - V_e[NL] \tag{10}$$

The water use in the Netherlands is calculated as follows:

$$WU[NL] = \sum_{p=1}^{n} Prod[NL, p] \cdot vwc[NL, p] \tag{11}$$

The gross virtual-water import is calculated based on the imported quantity and the virtual-water content of all products and countries:

$$V_i[NL] = \sum_{p=1}^{n} \sum_{c=1}^{m} I[c, p] \cdot vwc[c, p] \tag{12}$$

The gross virtual-water export is calculated based on the exported quantity (*E*, tons/year) and the average virtual-water content of all products exported from the Netherlands:

$$V_e[NL] = \sum_{p=1}^{n} E[NL, p] \cdot vwc^*[NL, p] \tag{13}$$

The average virtual-water content of an exported product is estimated by applying the same assumption that was used in the bottom-up approach (Eq. (9)).

The bottom-up and top-down calculations of the water footprint of a country for a particular year theoretically result in the same figure, provided that there is no product stock change over a year. The top-down calculation can theoretically give a slightly higher (lower) figure if the stocks of water-intensive products increase (decrease) over the year. The reason is that the top-down approach presupposes a balance (V_i plus *WU* becomes *WF* and V_e) which is an approximation only (to be more precise: V_i plus *WU* becomes *WF* plus V_e plus virtual-water stock increase). Another drawback of the top-down approach is that there can be delays between the moment of water use for production and the moment of trade. For instance in the case of trade in livestock products this may happen: beef or leather products traded in 1 year originate from livestock raised and fed in previous years. Part of the water virtually embedded in beef or leather refers to water that was used to grow feed crops in previous years. As a result of this, the virtual-water balance presumed in the top-down approach ($WU[NL]+V_i[NL]=WF[NL]+V_e[NL]$) will hold over a period of a few years, but not necessarily over 1 year.

Next to theoretical differences between the two approaches, differences can result from the use of different types of data as inputs of the calculations. The bottom-up approach depends on the quality of consumption data, while the top-down-approach relies on the quality of trade data. When the different databases are not consistent with one another, the results of both approaches will differ.

In one particular type of case the outcome of the top-down can be very vulnerable to relatively small errors in the input data. This happens when the import and export of a country are large relative to its domestic production, which is typical for a trade nation as the Netherlands. In this case the water footprint, calculated in the top-down approach as the domestic water use plus the virtual-water import minus the virtual-water export, will be sensitive to the import and export data used. Relative small errors in the estimates of virtual-water import and export translate into a relatively large error in the water footprint estimate. In such a case, the bottom-up approach will yield a more reliable estimate than the top-down approach. In countries where trade is relatively small compared to domestic production, the reliability of the outcomes of both approaches will depend on the relative quality of the databases used for each approach. In the case of agricultural products, both calculations are carried out in this study. However, the water footprint outcomes from the bottom-up approach are used as a basis for further analysis. For industrial products only top-down calculations are carried out. In the case of industrial products, no distinction between different types of industrial commodities is made, thus effectively industrial products are regarded as one homogeneous category with an average virtual-water content per dollar.

In the present study we are interested in the external water footprint of Dutch consumers (WF_e) and the re-exported virtual-water ($V_{e,r}$). To determine these terms we use the following assumption, which we apply separately for the category of agricultural products and for the category of the industrial products:

$$WF_e[NL] = \frac{WF[NL]}{V_i[NL] + WU[NL]} \cdot V_i[NL] \tag{14}$$

This formula says that only a fraction of the gross virtual-water import can be said to be the external water footprint of the Dutch consumers and that this fraction is equal to the portion of virtual-water import plus use of domestic water that is to be attributed to consumption within the country.[1] The other portion of virtual-water import plus use of domestic water is exported and is therefore not part of the Dutch footprint. The term *WF* in above equation refers to the water footprint of the Dutch consumers. When calculating the external water footprint, the total water footprint as earlier calculated with the bottom-up approach has been taken. The external water footprint can be estimated for specific countries and products by assuming that the national ratio between the external water footprint and the total virtual-water import applies to all partner countries and imported products[2,3]:

$$WF_{\mathrm{e}}[NL,c,p] = \frac{WF_{\mathrm{e}}[NL]}{V_{\mathrm{i}}[NL]} \cdot V_{\mathrm{i}}[NL,c,p] \tag{15}$$

The external water footprint of Dutch consumers for an individual country and an individual product are respectively:

$$WF_{\mathrm{e}}[NL,c] = \sum_{p=1}^{n} WF_{\mathrm{e}}[NL,c,p] \tag{16}$$

$$WF_{\mathrm{e}}[NL,p] = \sum_{c=1}^{m} WF_{\mathrm{e}}[NL,c,p] \tag{17}$$

Many products are imported from countries in which they are not produced. Examples are cocoa products from Belgium and cotton products from Germany. For some product groups, world production is concentrated in specific regions. For these products we can estimate the ultimate place of origin based on world production data (FAO, 2007b). We do this for cotton, cocoa and coffee. For these products it is assumed that the water footprint in a non-producing country should be distributed over producing countries according to the same distribution of the world production. We only include producing countries from which the Netherlands is already importing directly.

2.3. Impact of the water footprint

In order to gather insight into the impacts of both Dutch consumption and re-exported virtual-water, both WF_{e}, and V_{i} as a whole are compared to indicators of water scarcity or stress. Water-scarcity indicators are always based on two basic ingredients: a measure of water demand or use and a measure of water availability.

The first commonly used indicator of water scarcity is population of an area divided by total runoff in that area, called the water competition level (Falkenmark, 1989) or water dependency (Kulshreshtha, 1993). Many authors take the inverse ratio, thus getting a measure of the per capita water availability. Falkenmark proposed to consider regions with more than 1700 m^3 per capita per year as 'water sufficient', which means that only general water management problems occur. Between 1000–1700 m^3/cap/year would indicate 'water stress', 500–1000 m^3/cap/year 'chronic water scarcity' and less than 500 m^3/cap/year 'absolute water scarcity'. This classification is based on the idea that 1700 m^3 of water per capita per year is sufficient to produce the food and other goods and services consumed by one person. In Falkenmark's indicator 'runoff' is taken as a measure of water availability. Runoff can refer to locally generated runoff (in FAO terminology then called the internal renewable water resources, IRWR), but it can also include inflows from other areas (in FAO terminology then called the total renewable water resources, TRWR).

A second common indicator of water scarcity is the ratio of water withdrawal in a certain area to total runoff in that area, called variously the water utilization level (Falkenmark, 1989), the withdrawal-to-availability ratio (Alcamo et al., 2000; Alcamo and Henrichs, 2002) or the use-to-resource ratio (Raskin et al., 1996).

The third indicator has been proposed by Smakhtin et al. (2004a,b), who have determined the withdrawal-to-availability ratio by basin.

All three water-scarcity indicators can be applied to either countries or river basins. The indicators of water scarcity enable us to estimate the Dutch share in the creation of water stress in a country. On weak soil the imprint of a footstep is deeper than that it is on solid ground, so the impact of a water footprint in a water-scarce area is larger than in an area where water is more abundant.

2.4. Green, blue and grey water footprint

For the products with the largest contribution to the external water footprint of the Netherlands in the identified hotspots we estimate the size of the green, blue and grey components in the total water footprint.

In the case of agricultural products, we estimate the volume of green water use by taking the minimum of the crop water requirement and the precipitation available to the crop over the cropping season. We assume that 60% of the rainfall in the cropping season is available to the crop. The difference between crop water requirement and the precipitation available to the crop over the cropping season gives an indication of the irrigation water requirement (i.e. blue water requirement). For the areas equipped for irrigation it is assumed that the irrigation water requirements were actually met. For estimating the green versus blue water footprint in agriculture, the following spatial-explicit data have been used:

- The main locations where specific crops are cultivated (*e.g.* Leff et al., 2004);
- The percentage of land equipped for irrigation (Döll and Siebert, 2000);
- Crop water requirements (Hoekstra and Chapagain, 2008).
- Monthly precipitation at meteorological station (Müller and Hennings, 2000).

In the case of agricultural products, estimation of the grey water footprint is done as follows. It is assumed that the quantity of nitrogen that reaches free flowing water bodies is 10% of the applied fertilization rate (in kg/ha/year), presuming a steady state balance at root zone in the long run (Hoekstra and Chapagain, 2008). The effect of the use of other nutrients, pesticides and herbicides to the environment has not been analyzed. The total volume of water required per ton N is calculated considering the volume of nitrogen leached (ton/ton) and the maximum allowable concentration in the free flowing surface water bodies. The standard recommended by EPA (2005) for nitrate in drinking water is 10 mg/l (measured as nitrogen) and has been taken to calculate the necessary dilution water volume. This is a conservative approach, since natural background concentration of N in the water used for dilution has been assumed negligible. Data on the application of fertilizers has been obtained from the FERTISTAT database of FAO (FAO, 2007c).

In the case of industrial products data on water withdrawals from FAO (2007a) have been used. Part of this volume evaporates (blue water footprint), while the other part generally returns as polluted water to the water system (grey water footprint). In the cases where industrial wastewater flows are partially treated, we have thus overestimated the grey water footprint. On the other hand, the effect of pollution has been underestimated, because 1 m^3 of wastewater generally does not result in 1 m^3 of polluted water, but much more

[1] This assumption implies that $\frac{WF_{\mathrm{e}}}{V_{\mathrm{e,r}}} = \frac{WF_{\mathrm{i}}}{V_{\mathrm{e,d}}} = \frac{WF}{V_{\mathrm{e}}}$ and $\frac{WF_{\mathrm{e}}}{WF_{\mathrm{i}}} = \frac{V_{\mathrm{e,r}}}{V_{\mathrm{e,d}}} = \frac{V_{\mathrm{i}}}{WU}$.

[2] We have made an exception for cocoa products and derivates, because of the exceptionally high volumes that are imported and re-exported again. The national ratio between WF_{e} and V_{i} is not a good assumption here. Instead, we have applied a specific ratio of WF_{e} to V_{i} valid to the cocoa product category.

[3] For cotton we applied the top-down approach for estimating the water footprint, because data on cotton product consumption are not available in the consumption database used in this study (FAO, 2007b). Because the Netherlands does not have cotton production, we could now assume that $WFe = V_{\mathrm{i}} - V_{\mathrm{e}}$.

(Postel et al., 1996). On average, 10% of industrial water withdrawals are lost through evaporation (Shiklomanov and Rodda, 2003). In this report we assume that in the estimated water footprints related to industrial products, 10% is a blue water footprint and 90% is a grey water footprint. Results of this study are based on data for the period of 1996–2005. Most results are presented as 10-year averages, although in some cases specific annual data are shown. The product coverage of the study is comprehensive: the trade analysis covers all agricultural and industrial product categories as represented in the trade database of ITC (2006) and the consumption analysis covers all consumption categories available within the food balance sheets of the FAO (2007b). Table 1 gives an overview of all input sources used in this study.

2.5. Methodological innovation

The calculation methods applied in this study are the same as in earlier world-wide studies on virtual-water trade and water footprints (Hoekstra and Chapagain, 2007a, 2008; Chapagain and Hoekstra, 2008; Chapagain et al., 2006b) and one that was applied to the Netherlands in more specific terms (Hoekstra and Chapagain, 2007b). There are, however, two methodological improvements when compared to this earlier study. Firstly, the bottom-up approach is applied to calculate the water footprint which is more accurate for a country as the Netherlands, where trade flows are large if compared to domestic production. This approach has been tested earlier in a pre-study for the Netherlands; see Gerbens-Leenes and Hoekstra (2007). Secondly the virtual-water content of consumed and exported goods is calculated as a weighted average of domestically produced and imported products (the variable *vwc**) instead of taking the virtual-water content of the domestically produced products or the global average virtual-water content in the case that there is no domestic production.

Apart from the methodological improvements, there are differences between the earlier study and the current one in terms of the data used. In the current study we analyze the 10-year period 1996–2005 instead of a 5-year period 1997–2001, which diminishes the influence of inter-annual differences due to trade flow delays. Besides, more accurate data in the current study with respect to livestock feed composition are used. Finally, the current study extends the earlier study by making a first step from water footprint estimation towards impact assessment by comparing water footprints to water-scarcity indicators for the identification of hotspots.

Table 1
Overview of input variables and sources used.

Input variable	Source
Agricultural water use	
• Crop water requirement per crop per country	Hoekstra & Chapagain (2008)
• Agricultural yield per crop per country	FAOSTAT (FAO, 2007b)
• Livestock feed composition in the Netherlands	CBS (2007), Elferink and Nonhebel (2007), LEI (2007) PDV (2005)
• Livestock feed composition in other countries	Hoekstra & Chapagain (2008)
• Consumption per product	FAO's food balance sheets, which are part of FAOSTAT (FAO, 2007b); data available for 1996–2003; average for this period assumed for 2004–05.
• Agricultural production	FAO PRODSTAT FAO (2007b)
• Use of fertilizer for important crops in hotspots	FAO FERTISTAT FAO (2007c)
Domestic water use	
• Domestic water withdrawal in the Netherlands	AQUASTAT FAO (2007a); Vitens (2008)
Industrial water use	
• Industrial water withdrawal per country	AQUASTAT FAO (2007a)
• Added value in the industrial sector per country	UN Statistic Division (2007)
• Import and export of agricultural and industrial products	ITC (2006)
• Precipitation and renewable water resources per country	AQUASTAT FAO (2007a)

3. Results

3.1. The water footprint of Dutch consumers

The total water footprint of Dutch consumers is about 2300 m^3 per capita per year for the period 1996–2005. Agricultural goods are responsible for the largest part of the footprint (67%), industrial goods are responsible for 31% and domestic water use accounts for about 2% (Fig. 2).

The water footprint due to the consumption of agricultural products is specified further into product categories. Livestock products make up 31% of the water footprint. Oil crops and oil from oil crops are large contributors as well (12%). The consumption of coffee, tea, cocoa and tobacco contributes another 8% and cereals and beer, which is made from barley, contribute 5%. Cotton products and fruit contribute 4% and 3% respectively. The remainder of the footprint is related to other agricultural products (4%). A more detailed overview of the individual contribution of product categories to the water footprint of Dutch consumers is given in Table 2. In Table 3 the results of both the bottom-up and the top-down approach for the water footprint due to the consumption of agricultural products are given.

3.2. The external water footprint of Dutch consumers

About 11% of the water footprint of the Netherlands is internal and 89% is external. For the water footprint due to the consumption of agricultural products the external part is even 97%. For agricultural products, about 48% of the external water footprint is located within Europe (mainly in Germany, France and Belgium) and 20% in Latin America (mainly in Brazil and Argentina). For industrial products, 53% of the external water footprint is in Europe and about 33% in Asia (mainly China, Taiwan, Hong Kong and Viet Nam). Fig. 3 summarizes the results per continent, where Latin America includes Mexico, and Europe includes Turkey and the Russian Federation. During the period 1996–2005, the external water footprint in Latin America steadily increased, while the external water footprint in North America decreased. Fig. 3 also shows the external water footprint of the Dutch consumers per agricultural product category. The product categories and the percentages refer to products as imported, not as consumed. This partly

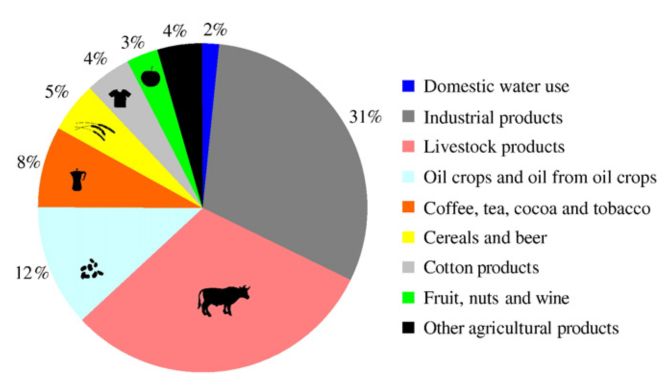

Fig. 2. The water footprint of Dutch consumers by product category. The total water footprint is 2300 m^3 per capita per year (population 16.3 million) for the period 1996–2005.

Table 2
Water footprint of the Dutch consumers related to consumption of agricultural products.

Product category	Water footprint(10^9 m^3)	
Livestock products	11.58	45.6%
Pig meat	2.24	8.8%
Milk — excluding butter	2.10	8.3%
Bovine meat	1.88	7.4%
Fats, animals, raw	1.85	7.3%
Eggs	1.50	5.9%
Poultry meat	1.47	5.8%
Mutton and goat meat	0.14	0.5%
Offals, edible	0.13	0.5%
Butter, ghee	0.02	0.1%
Honey	0.00	<0.1%
Cream	0.00	<0.1%
Meat, other	0.24	1.0%
Oil from oil crops	4.57	16.8%
Palm oil	1.04	4.1%
Coconut oil	0.48	1.9%
Sunflower seed oil	0.38	1.5%
Soya bean oil	0.19	0.8%
Palm kernel oil	0.15	0.6%
Rape and mustard oil	0.14	0.6%
Olive oil	0.12	0.5%
Groundnut oil	0.09	0.4%
Maize germ oil	0.09	0.3%
Cottonseed oil	0.01	<0.1%
Sesame seed oil	0.01	<0.1%
Oil crops oil, other	1.57	6.3%
Coffee, tea, cocoa beans	2.98	11.7%
Coffee	2.38	9.4%
Tea	0.46	1.8%
Cocoa beans	0.14	0.5%
Cereals	1.74	6.9%
Wheat	1.46	5.7%
Rice (milled equivalent)	0.15	0.6%
Maize	0.07	0.3%
Oats	0.02	0.1%
Barley	0.01	0.1%
Rye	0.01	<0.1%
Cereals, other	0.01	<0.1%
Cotton products	1.65	6.5%
Fruits	1.03	4.0%
Oranges, mandarins	0.36	1.4%
Apples	0.11	0.4%
Grapes	0.08	0.3%
Bananas	0.08	0.3%
Grapefruit	0.05	0.2%
Pineapples	0.03	0.1%
Lemons, limes	0.01	< 0.1%
Dates	0.00	<0.1%
Plantains	0.00	<0.1%
Citrus, other	0.00	<0.1%
Fruits, other	0.31	1.2%
Sweeteners	0.73	2.9%
Sugar (raw equivalent)	0.32	1.2%
Sweeteners, other	0.42	1.6%
Beverages	0.8	1.5%
Beer	0.22	0.9%
Wine	0.15	0.6%
Beverages, alcoholic	0.01	<0.1%
Beverages, fermented	0.00	<0.1%
Tree nuts	0.30	1.2%
Roots and tubers	0.24	1.0%
Potatoes	0.24	1.0%
Oil crops	0.15	0.6%
Coconuts — incl. copra	0.08	0.3%
Olives	0.02	0.1%
Groundnuts (shelled eq.)	0.02	0.1%
Rape and mustard seed	0.01	<0.1%
Soya beans	0.00	<0.1%
Cottonseed	0.00	<0.1%
Oil crops, other	0.02	0.1%
Vegetables	0.14	0.6%
Onions	0.02	0.1%
Tomatoes	0.01	<0.1%
Vegetables, other	0.12	0.5%
Spices	0.14	0.6%
Pepper	0.04	0.2%
Cloves	0.04	0.1%
Pimento	0.03	0.1%
Spices, other	0.03	0.1%
Pulses	0.05	0.2%
Beans	0.02	0.1%
Peas	0.02	0.1%
Pulses, other	0.02	0.1%

explains the difference with Fig. 2, which shows the total water footprint (internal + external) by product as consumed. For instance, the product categories of ‘cereals’ and ‘oil crops’ in Fig. 3 include imported feed for the Dutch livestock sector.

The water footprint of Dutch consumers is one variable out of a set of nine variables that together give an overview of the Dutch water accounts. As can be seen from the numbers in Fig. 1, the Netherlands, as a trade nation, imports not only for the purpose of domestic consumption. More than half of the virtual-water import is re-exported again. Part of the re-export of virtual-water is done after having processed imported raw materials. An example of such processing is related to the Dutch livestock sector. Crops are imported from Asia and Latin America to be used as feed for Dutch livestock, while large volumes of cheese, eggs and meat are exported.

The sector-specific water accounts are given in Table 4. The geographical spreading of the external water footprint insofar related to the consumption of industrial products differs considerably from the geographical distribution of the external water footprint related to the consumption of agricultural products. Tables 5 and 6 show the ten largest contributors to the external footprint of agricultural and the external footprint of industrial products, respectively. In Fig. 4 country-specific contributions to the external footprint are presented geographically by product category: agricultural products, industrial products, feed for livestock products, oil crops and oil from oil crops, coffee, cereals and beer, cotton products and fruit, nuts and wine. To show the external water footprint due to the consumption of livestock products the origin of crops used for feeding livestock in the Netherlands are analyzed. Therefore, the foreign water use for a number of these crops and derivates, including soybeans, soybean scrap, cassava, sugar cane molasses, and citrus pulp are aggregated. For coffee, cocoa and cotton products we have redistributed virtual-water imports from non-producing countries over producing countries taking into account the share of these producing countries in world production of these products.

3.3. The total virtual-water import to the Netherlands

About 44% of the virtual-water import to the Netherlands relates to products consumed in the Netherlands, thus constituting the external water footprint. This means that the other 56% of the virtual-water imported to the Netherlands is re-exported (60% in the case of agricultural products and 40% in the case of industrial products). Fig. 5 shows, for agricultural products, the distribution of virtual-water import over the six continents. Not all imports are for Dutch consumption; virtual-water re-export concerns for instance cocoa beans from Africa (mainly Cote d'Ivoire, Ghana, Cameroon and Nigeria). After processing in the Netherlands into cocoa butter, cocoa powder or cocoa paste, the cocoa is re-exported to other European countries (mainly Germany, the United Kingdom, Belgium and Switzerland).

When the water footprint of the Netherlands over time (as estimated with the bottom-up approach, see Table 3) is compared to the virtual-water import to the country, it is found that the latter is

Table 3
Water footprint of Dutch consumers related to consumption of agricultural products, estimated according to the top-down and bottom-up approach.

Year	Top-down approach (water footprint as the closing entry)				Bottom-up approach (virtual-water export as the closing entry)			
	A	*B*	*C*	*D* = *A* + *B* − *C*	*A*	*B*	*E* = *A* + *B* − *F*	*F*
	Virtual-water import (Gm^3/year)	Water use (Gm^3/year)	Virtual-water export (Gm^3/year)	Water footprint (Gm^3/year)	Virtual-water import (Gm^3/year)	Water use (Gm^3/year)	Virtual-water export (Gm^3/year)	Water footprint (Gm^3/year)
1996	60.1	3.1	34.5	28.7	60.1	3.1	39.7	23.5
1997	47.7	3.1	39.9	10.9	47.7	3.1	28.0	22.8
1998	54.4	2.9	38.1	19.2	54.4	2.9	33.3	23.9
1999	65.6	3.0	41.5	27.2	65.6	3.0	42.0	26.7
2000	64.1	3.1	42.3	24.8	64.1	3.1	41.5	25.7
2001	69.3	3.0	43.2	29.2	69.3	3.0	44.8	27.5
2002	42.4	3.1	34.7	10.7	42.4	3.1	18.5	27.0
2003	70.5	3.0	40.2	33.3	70.5	3.0	47.5	26.0
2004	70.1	3.1	44.1	29.1	70.1	3.1	47.3	25.9
2005	71.2	3.0	45.4	28.8	71.2	3.0	49.4	24.8
Average	61.5	3.0	40.4	24.2	61.5	3.0	39.1	25.4

much more variable over time. Where consumption over time is rather constant, the trade balance, domestic production and over-year storage vary more significantly. Fig. 5 shows that the virtual-water import was incidentally low in the year 2002, which is mainly due to a low import volume for various water-intensive products in that particular year.

3.4. Hotspots

Hotspots — i.e. countries where the impact of the Dutch external water footprint is relatively large — have been selected based on a country's share in the total external water footprint of Dutch consumers and the three indicators of water scarcity. The impact is obviously larger when the footprint is relatively large in a place where water scarcity is relatively large as well. The selection of hotspots has been done at country level, which implies that local hotspots, where impacts at national level are not among the most significant, have been ignored. The countries that turn out as hotspots are: China; India; Spain; Turkey; Pakistan; Sudan; South Africa; and Mexico. Tables 7 and 8 summarize the most important findings with respect to

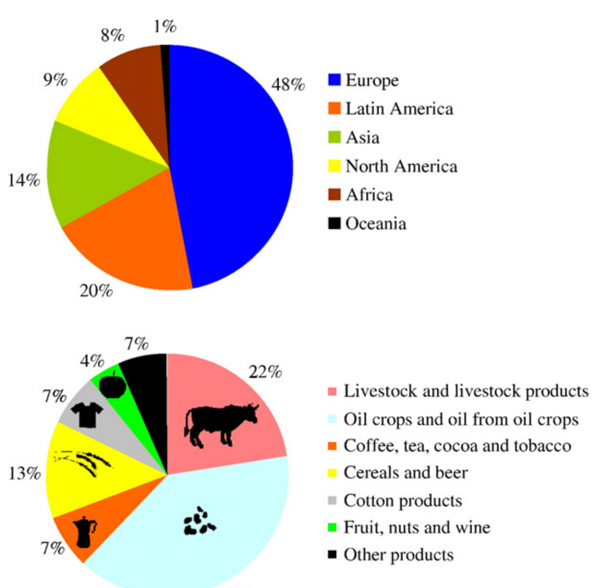

Fig. 3. Distribution of the external water footprint of Dutch consumption due to the consumption of agricultural products by continent (top) and by product (bottom). The product categories and the percentages refer to products as imported, not as consumed.

the selected hotspots. With the exception of China, the external water footprint in these countries is mainly due to the consumption of agricultural products (Fig. 6). In China, the water footprint is to a large extent related to the production of industrial goods for the Dutch consumer market. The water footprint related to industrial goods consists mostly (90%) of a grey water footprint (pollution), the remainder (10%) being a blue water footprint (evaporation of ground and surface water). In the other hotspots, the water footprint is dominated by agricultural products. The type of agricultural products in the hotspots varies greatly as is shown in Fig. 6. The ratio of the blue

Table 4
The Dutch water accounts specified by consumption category.

	Related to domestic water use (Gm^3/year)	Related to agricultural products (Gm^3/year)	Related to industrial products (Gm^3/year)	Total (Gm^3/year)
Use of domestic water resources (*WU*)	0.6	3.0	4.8	8.4
Virtual-water import (V_i)	–	61.5	14.3	75.8
Virtual-water export (V_e)	–	39.1	7.6	46.7
• Related to export of domestically produced products ($V_{e,d}$)	–	2.2	1.9	4.1
• Related to re-export of imported products ($V_{e,r}$)	–	36.9	5.7	42.6
Water footprint (*WF*)	0.6	25.4	11.5	37.5
• Internal water footprint (*WFi*)	0.6	0.8	2.9	4.3
• External water footprint (WF_e)	–	24.6	8.6	33.2

Period 1996–2005.

Table 5
The largest contributors to the external water footprint related to Dutch consumption of agricultural products.

Country	Part of external water footprint (related to the consumption of agricultural products)
Germany	18.3%
Brazil	9.7%
France	8.7%
United States	8.6%
Belgium–Luxembourg	8.2%
Argentina	5.4%
Indonesia	4.1%
Malaysia	2.5%
India	2.2%
Thailand	1.9%

Table 6
The largest contributors to the external water footprint related to Dutch consumption of industrial products.

Country	Part of external water footprint (related to the consumption of industrial products)
China	15.2%
United States	11.0%
Germany	10.6%
Russian Federation	10.6%
Belgium–Luxembourg	9.9%
Taiwan (POC)	6.6%
France	5.6%
Hong Kong	3.3%
Viet Nam	2.4%
Poland	2.1%

to the green water footprint per hotspot depends on the degree of irrigation at these hotspots.

4. Conclusion

The total water footprint of the Netherlands is estimated to be about 2300 m^3/year/cap, which is nearly double the water footprint of an average world citizen. About 67% of the Dutch water footprint relates to the consumption of agricultural goods, 31% to the consumption of industrial goods, and 2% to domestic water use. The Dutch water footprint related to the consumption of agricultural goods, is composed as follows: 46% related to livestock products; 17% oil crops and oil from oil crops; 12% coffee, tea, cocoa and tobacco; 8% cereals and beer; 6% cotton products; 5% fruits; and 6% other agricultural products. Most agricultural products are related to food

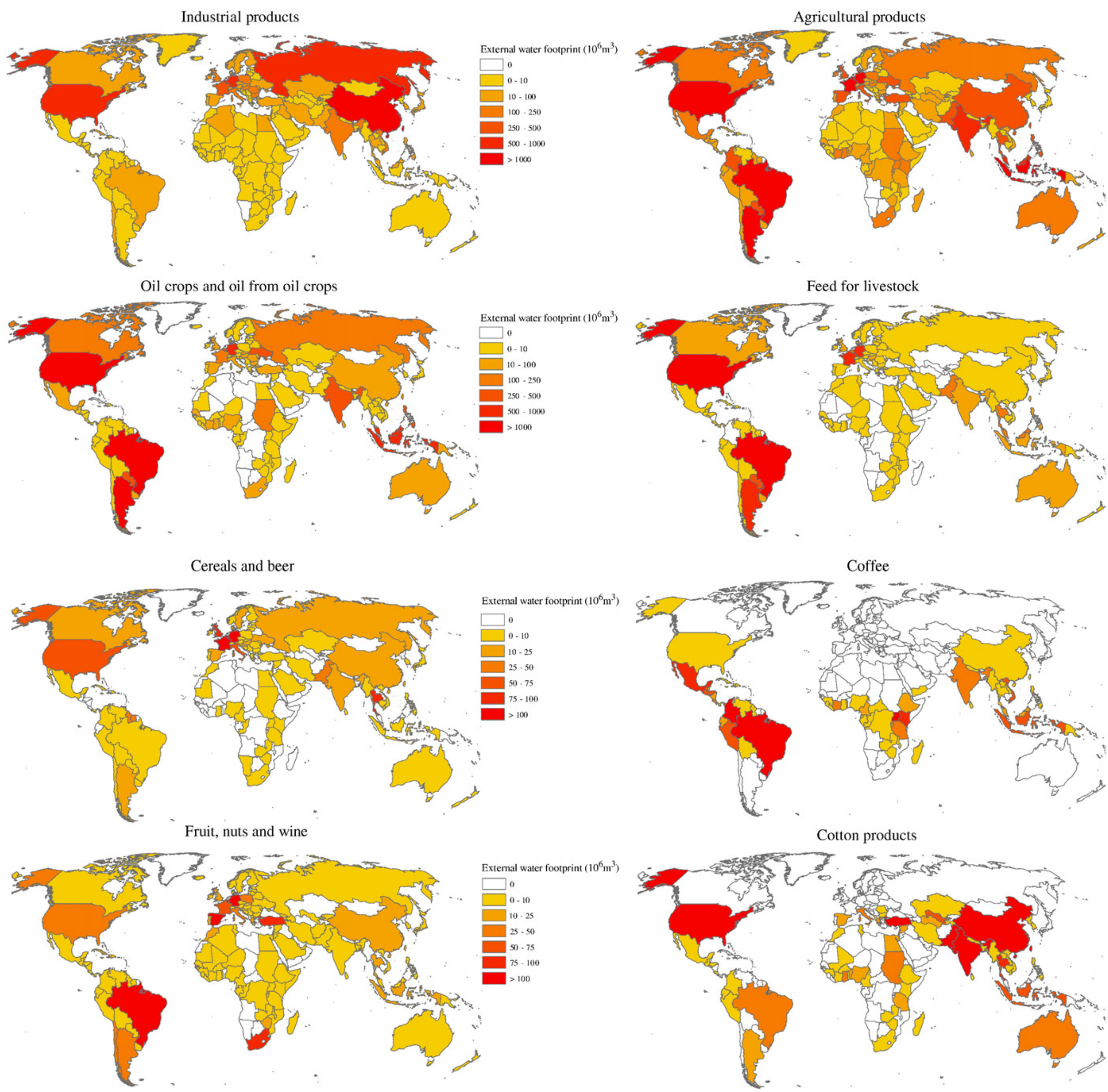

Fig. 4. Geographical distribution of the external water footprint of the Netherlands for selected product categories.

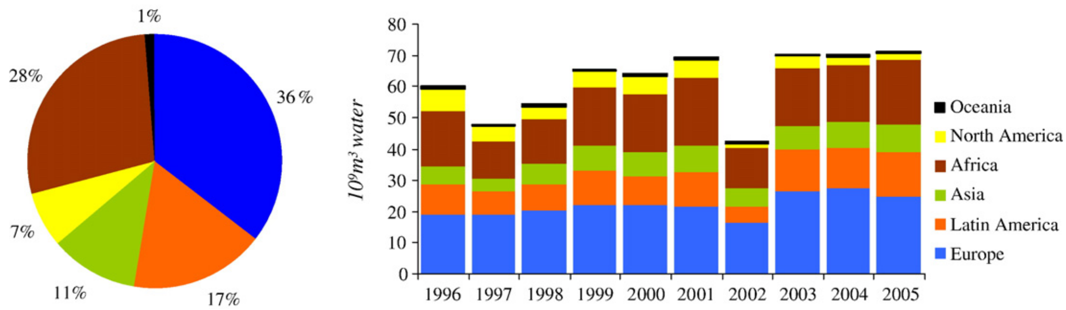

Fig. 5. Geographical distribution of the virtual-water import insofar related to the import of agricultural products specified by continent. Left: average over the period 1996–2005. Right: variation over this period.

consumption, most important exceptions being cotton for textiles and oil crops for cosmetics, pharmaceuticals, soaps, lubricants, paints and bio-energy.

About 89% of the water footprint of the Netherlands is external. About 48% of this external footprint is located within European countries (mainly in Germany, France and Belgium) and 20% in Latin

Table 7
Hotspots and the products contributing to the external water footprint of Dutch consumers.

Country	External water footprint related to industrial products (10^6 m^3/year)[a]	External water footprint related to agricultural products (m^3/year)					
		Total (10^6 m^3/year)	Product category with largest contribution	Contribution of the product category	Main product within product category	Green	Blue
China	1307	393	Fibres (including cotton)	65%	Cotton (100%)	62%	38%[b]
			Oil crops and oil from oil crops	16%	Groundnuts (74%)	90%	10%
			Livestock products	7%	Skin and hair of pigs (90%)		
India	123	547	Oil crops and oil from oil crops	46%	Castor oil seed (72%)	82%	18%
			Fibres (including cotton)	35%	Cotton (100%)	75%	25%[b]
			Coffee, tea, cocoa and tobacco	10%	Coffee (72%)	79%	21%
Spain	63	305	Fruits (including wine)	46%	Citrus fruit (36%), wine, grapes, raisins (28%)	60%	40%
			Livestock products	27%	Cattle (42%), pig (27%) and goat (20%)		
Turkey	39	340	Fibres (including cotton)	60%	Cotton (99%)	9%	91%[b]
			Fruits (including wine)	23%	Raisins (81%)	91%	9%
			Coffee, tea, cocoa and tobacco	7%	Tobacco (84%)	93%	7%
Pakistan	17	305	Fibres (including cotton)	54%	Cotton (100%)	21%	79%[b]
			Sugar (including sugar crops)	33%	Cane molasses (100%)	8%	92%
Sudan	<1	218	Oil crops and oil from oil crops	79%	Sesame seed (89%)	81%	19%
South Africa	6	145	Fruits (including wine)	49%	Citrus fruit (35%), grapes, wine, raisins (29%)	80%	20%
			Oil crops and oil from oil crops	34%	Groundnut/oil (56%), sunflower seed (40%)	81%	19%
Mexico	7	123	Coffee, tea, cocoa and tobacco	66%	Coffee (100%)	57%	43%
			Oil crops and oil from oil crops	16%	Sunflower oil (75%)	100%	0%

[a] Industrial water footprints estimated to be 10% blue and 90% grey.
[b] Based on Chapagain et al. (2006a).

Table 8
Estimated grey water footprint for specific crops at the hotspots.

		Area (km^2)[a]	Area with fertilizer (%)[a]	Rate N (kg/ha)[a]	Rate P (kg/ha)[a]	Rate K (kg/ha)[a]	Grey water footprint (m^3/ha)[b]
China, Mainland (1997)	Cotton	5528	100	120	70	25	1200
	Oil crops	668	95	65	40	30	618
India (2003/2004)	Cotton	8500	6	90	23	5	54
	Other crops	60,400	22	35	19	7	77
Spain (1999/2000)	Fruits	4975	n.a.	57	24	26	n.a.
Turkey (1999)	Cotton	718	99	127	39	4	1257
	Fruits	1240	70	<0.1	<0.1	<0.1	0.4
	Tobacco	289	68	3	1	6	20
Pakistan (2001/2002)	Cotton	n.a.	n.a.	120	50	0.1	n.a.
	Sugar cane	n.a.	n.a.	125	56	0.3	n.a.
Sudan[a]		n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
South Africa (2004)	Citrus fruits	64	100	80	35	60	800
	Sunflower	640	85	15	21	2	128
Mexico (1998)	Coffee	679	60	60	40	15	360
	Sunflower	123	80	75	10	0	600

[a] Source: FAO (2007c). For Sudan, no data on fertilizer use are available.
[b] Assumptions: nitrogen is the critical factor; 10% of the nitrogen leaches to the water system; nitrogen water standard 10 mg/l (Hoekstra and Chapagain, 2008).

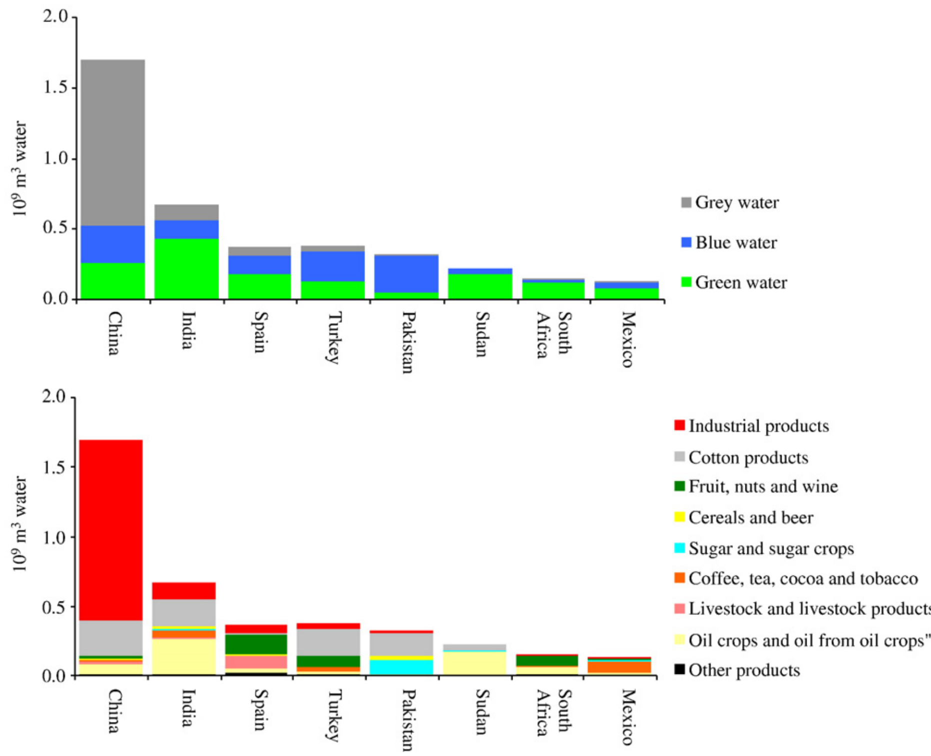

Fig. 6. Composition of the external water footprint of Dutch consumers per hotspot country and by type of water footprint (top) and product category (bottom).

American countries (mainly in Brazil and Argentina). For industrial products 53% of the consumed products originate from European countries and about 33% originates from Asian countries (mainly China, Taiwan, Hong Kong and Viet Nam).

As a trade nation, the Netherlands imports not only for the purpose of domestic consumption. Only 44% of the virtual-water import relates to products consumed in the Netherlands, thus constituting the external water footprint. For agricultural products this is 40% and for industrial products this is 60%. The remaining 56% of the virtual-water import to the Netherlands is re-exported. About 41% of the virtual-water import for re-export comes from Africa (mainly Cote d'Ivoire, Ghana, Cameroon and Nigeria) and mainly concerns the import of cocoa beans, most of which are processed in the Netherlands into cocoa butter, cocoa powder or cocoa paste and re-exported to other European countries (mainly Germany, United Kingdom, Belgium and Switzerland).

The impact of the external water footprint of Dutch consumers is highest in countries that experience serious water scarcity. Based on indicators for water scarcity the following eight countries have been identified as hotspots: China; India; Spain; Turkey; Pakistan; Sudan; South Africa; and Mexico. Although these countries are not the largest contributors to the external water footprint of Dutch consumers in absolute terms, the impact of Dutch consumption in these countries deserves serious attention since in these countries the negative externalities of Dutch consumption are considered to be most serious.

The study shows that Dutch consumption implies the use of water resources throughout the world, with significant impacts at specified locations. This knowledge is relevant for consumers, government and businesses when addressing the sustainability of consumer products and supply chains. The results of this study can be an input to bilateral cooperation between the Netherlands and the Dutch trade partners aimed at the reduction of the negative impacts of Dutch consumption on foreign water resources. Dutch government can also engage with businesses in order to stimulate them to review the sustainability of their supply chains.

Acknowledgments

This study was carried out in commission of the Netherlands Environmental Assessment Agency (MNP), Bilthoven, the Netherlands.

References

Alcamo, J., Henrichs, T., Rösch, T., 2000. World Water in 2025: global modelling and scenario analysis for the World Commission on Water for the 21st century. Kassel World Water Series, Report, No.2, University of Kassel.
Alcamo, J., Henrichs, T., 2002. Critical regions: a model-based estimation of world water resources sensitive to global changes. Aquatic Sciences 64 (4), 352–362.
CBS, 2007. Land- en tuinbouwcijfers 2007. Statistics Netherlands, Voorburg.
Chapagain, A.K., Hoekstra, A.Y., 2008. The global component of freshwater demand and supply: an assessment of virtual water flows between nations as a result of trade in agricultural and industrial products. Water International 33 (1), 19–32.
Chapagain, A.K., Hoekstra, A.Y., Savenije, H.H.G., Gautam, R., 2006a. The water footprint of cotton consumption: an assessment of the impact of worldwide consumption of cotton products on the water resources in the cotton producing countries. Ecological Economics 60 (1), 186–203.
Chapagain, A.K., Hoekstra, A.Y., Savenije, H.H.G., 2006b. Water saving through international trade of agricultural products. Hydrology And Earth System Sciences 10 (3), 455–468.
Döll, P., Siebert, S., 2000. A digital global map of irrigated areas. ICID Journal 49 (2), 55–66.
Elferink, E.V., Nonhebel, S., 2007. Variations in land requirements for meat production. Journal of Cleaner Production 15 (18), 1778.
EPA, 2005. List of Drinking Water Contaminants: Ground Water and Drinking Water. US Environmental Protection Agency.
Falkenmark, M., 1989. The massive water scarcity now threatening Africa: why isn't it being addressed? Ambio 18 (2), 112–118.
FAO, 2007a. AQUASTAT Database. Food and Agriculture Organization, Rome. www.fao.org/nr/water/aquastat.
FAO, 2007b. FAOSTAT Database. Food and Agriculture Organization, Rome. http://faostat.fao.org.
FAO, 2007c. FERTISTAT — Fertilizer Use by Crop Statistics Database. Food and Agriculture Organization, Rome. http://www.fao.org/ag/agl/fertistat.
Gerbens-Leenes, P.W., Hoekstra, A.Y., 2007. The water footprint of the Netherlands: analysis of international impacts and options for change. Civil Engineering & Management Research Report 2007R-008. InUniversity of Twente, Enschede.
Hoekstra, A.Y., Chapagain, A.K., 2007a. Water footprints of nations: water use by people as a function of their consumption pattern. Water Resources Management 21 (1), 35–48.

Hoekstra, A.Y., Chapagain, A.K., 2007b. The water footprints of Morocco and the Netherlands: Global water use as a result of domestic consumption of agricultural commodities. Ecological Economics 64 (1), 143–151.

Hoekstra, A.Y., Chapagain, A.K., 2008. Globalization of Water: Sharing the Planet's Freshwater Resources. Blackwell Publishing, Oxford, UK.

ITC, 2006. SITA — Statistics for International Trade Analysis. International Trade Centre. www.intracen.org/mas/sita.htm.

Kulshreshtha, S.N., 1993. World water resources and regional vulnerability: impact of future changes. Research Report RR-93-10. International Institute for Applied Systems Analysis, Laxenburg, Austria.

Leff, B., Ramankutty, N., Foley, J.A., 2004. Geographic distribution of major crops across the world. Global Biogeochemical Cycles 18 (1).

LEI, 2007. Landbouw Economisch Bericht 2007.

Ma, J., Hoekstra, A.Y., Wang, H., Chapagain, A.K., Wang, D., 2006. Virtual versus real water transfers within China. Philosophical Transactions of the Royal Society of London. B 361 (1469), 835–842.

Müller and Hennings (2008) CLIMATE 1 — The Global Climate Data Atlas on CD-ROM, Univ. Flensburg, Inst. F. Geografie, Flensburg

PDV, 2005. Herkomst en samenstelling voer voor de Nederlandse intensieve veehouderij. Productschap Diervoeder.

Postel, S.L., Daily, G.C., Ehrlich, P.R., 1996. Human appropriation of renewable fresh water. Science 271, 785–788.

Raskin, P.D., Hansen, E., Margolis, R.M., 1996. Water and sustainability: global patterns and long-range problems. Natural Resources Forum 20 (1), 1–5.

Shiklomanov, I.A., Rodda, J.C., 2003. World Water Resources at the Beginning of the Twenty-first Century. Cambridge University Press, Cambridge.

Smakhtin, V., Revenga, C., Döll, P., 2004a. Taking into account environmental water requirements in global-scale water resources assessments. Comprehensive Assessment Research Report 2, IWMI, Colombo, Sri Lanka.

Smakhtin, V., Revenga, C., Doll, P., 2004b. A pilot global assessment of environmental water requirements and scarcity. Water International 29 (3), 307–317.

UN Statistic Division (2007) http://unstats.un.org/unsd/snaama/selectionbasicFast.asp.

Vitens (2008) www.verswater.nl.