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ANALYSIS

The water footprint of coffee and tea consumption in the Netherlands

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ABSTRACT

A cup of coffee or tea in our hand means manifold consumption of water at the production location. The objective of this study is to assess the global water footprint of the Dutch society in relation to its coffee and tea consumption. The calculation is carried out based on the crop water requirements in the major coffee and tea exporting countries and the water requirements in the subsequent processing steps. In total, the world population requires about 140 billion cubic metres of water per year in order to be able to drink coffee and tea. The standard cup of coffee and tea in the Netherlands costs about 140 l and 34 l of water respectively. The largest portions of these volumes are attributable to growing the plants. The Dutch people account for 2.4% of the world coffee consumption. The total water footprint of Dutch coffee and tea consumption amounts to 2.7 billion cubic metres of water per year (37% of the annual Meuse runoff). The water needed to drink coffee or tea in the Netherlands is not Dutch water. The most important sources for the Dutch coffee are Brazil and Colombia and for the Dutch tea Indonesia, China and Sri Lanka. The major volume of water to grow the coffee plant comes from rainwater. For the overall water need in coffee production, it makes hardly any difference whether the dry or wet production process is applied, because the water used in the wet production process is a very small fraction (0.34%) of the water used to grow the coffee plant. However, the impact of this relatively small amount of water is often significant. First, it is blue water (abstracted from surface and ground water), which is sometimes scarcely available. Second, the wastewater generated in the wet production process is often heavily polluted.

1. Introduction

Growing environmental awareness has made people more frequently ask the question: what are the hidden natural resources in a product? Which and what quantum of natural resources were needed in order to enable us to consume a certain product? Coffee and tea consumption is possible through the use of natural and human resources in the producing countries. One of the natural resources required is water. There is a water need for growing the plant, but there is also a need for water to process the crop into the final product.

When there is a transfer of a product from one place to another, there is little direct physical transfer of water (apart from the water content of the product, which is quite insignificant in terms of volume). There is, however, a significant transfer of water in virtual sense. The 'virtual water content' of a product is understood here as the volume of water that is required to produce the product. Coffee and tea

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producing countries export immense volumes of 'virtual water' to the consumer countries. Thus the importing countries are indirectly employing the water in the producing countries. As a result, consumers generally have little idea of the resources needed to enable them to consume. This paper is meant to assess the volume of water needed to have the Dutch drink coffee and tea.

The roots of coffee consumption are probably in Ethiopia. The coffee tree is said to originate in the province of Kaffa (ICO, 2003). Coffee spread to the different parts of the world in the 17th and 18th century, the period of colonisation. Early 18th century the Dutch colonies had become the main suppliers of coffee to Europe. Today people drink coffee all over the world. The importance of coffee to people cannot be overestimated. Coffee is of great economic importance to the producing, mostly developing countries, and of considerable social importance to the consuming countries.

Tea is the dried leaf of the tea plant. Indigenous to both China and India, the plant is now grown in many countries around the world. Tea was first consumed as a beverage in China sometime between 2700 BC and 220 AD. The now traditional styles of green, black and oolong teas first made an appearance in the Ming Dynasty in China (1368–1644 AD). Tea began to travel as a trade item as early as the fifth century with some sources indicating Turkish traders bartering for tea on the Mongolian and Tibetan borders. Tea made its way to Japan late in the sixth century, along with another Chinese export product — Buddhism. By the end of the seventh century, Buddhist monks were planting tea in Japan. Tea first arrived in the west via overland trade into Russia. Certainly Arab traders had dealt in tea prior to this time, but no Europeans had a hand in tea as a trade item until the Dutch began an active and lucrative trade early in the seventeenth century. Dutch and Portuguese traders were the first to introduce Chinese tea to Europe. The Portuguese shipped it from the Chinese coastal port of Macao; the Dutch brought it to Europe via Indonesia. From Holland, tea spread relatively quickly throughout Europe. Although drunk in varying amounts and different forms, tea is the most consumed beverage in the world next to water. Tea is grown in over 45 countries around the world, typically between the Tropics of Cancer and Capricorn (FAO, 2003c). The study is limited to tea made from the real tea plant, of which the two main varieties are *Camellia sinensis* and *Camellia assamica*. This excludes other sorts of 'tea', made from other plants, such as 'rooibos tea' (from a reddish plant grown in South Africa), 'honeybush tea' (related to rooibos tea and also grown in South Africa), 'yerba mate' (from a shrub grown in some Latin American countries), and 'herbal tea' (a catch-all term for drinks made from leaves or flowers from various plants infused in hot water).

The impact of human consumption on the global water resources can be mapped with the concept of the 'water footprint', a concept introduced by Hoekstra and Hung (2002) and subsequently elaborated by Chapagain and Hoekstra (2004). The water footprint of a nation can be quantified as the total volume of freshwater that is used to produce the goods and services consumed by the inhabitants of the nation. The water footprint shows water demand related to consumption within a nation, while the traditional indicator of water demand (i.e. total water withdrawal for the various sectors of economy) shows water demand in relation to production within a nation. Besides, the water footprint shows not only the use of groundwater and surface water (so-called 'blue water', see Falkenmark, 2003) but also the use of infiltrated rainwater ('green water'). Finally, the water footprint includes a spatial dimension by visualizing how consumers in one particular part of the world indirectly employ the water resources in various other parts of the world.

The water footprint concept is an analogue of the ecological footprint concept that was introduced by Rees (1992) and Wackernagel and Rees (1996). Where the ecological footprint denotes the area (hectares) needed to sustain a population, the water footprint represents the water volume (cubic metres per year) required. Methodologically the water footprint calculation deviates a bit from the ecological footprint calculation: the water footprint explicitly considers the actual location of the water use, whereas the ecological footprint does not consider the actual place of land use. The water footprint of a nation thus accounts for the actual volumes of water use at the various locations where the water is appropriated, while the ecological footprint is calculated based on a global average land requirement per consumption category. By uncovering the spatial link between place of consumption and locations of resource use, we hope to stimulate debate about consumer's responsibility for the impacts of production at distant locations, recognizing the fact that not all impacts are properly translated into a fair price paid by the consumer. In particular in the case of water use, generally no more than a small fraction of the full cost of water (including opportunity costs, negative externalities and a scarcity rent) is charged to the consumers of water-based commodities (UNESCO, 2003, 2006).

In an earlier article we assessed the global water footprint of cotton consumption (Chapagain et al., 2006). The objective of the current study is to assess the global water footprint of the Dutch society in relation to its coffee and tea consumption. As a first step, we estimate the virtual water content of coffee and tea in each of the countries that export coffee or tea to the Netherlands. Next, we calculate the volumes of virtual water flows entering and departing the Netherlands in the period 1995–99 insofar as they are related to coffee and tea trade. Finally, we assess the volume of water needed to drink one cup of coffee or tea in the Netherlands. The water volume per cup multiplied by the number of cups consumed per year provides an estimate of the total Dutch annual water footprint related to coffee or tea consumption.

2. Virtual water content of coffee and tea in different production stages

The virtual water content of coffee or tea is the volume of water required to produce one unit of coffee or tea, generally expressed in terms of cubic metres of water per ton of coffee or tea. This is different in the different stages of processing. In the case of coffee, the virtual water content of fresh cherries is calculated based on the crop water requirement of the coffee plant (in m^3/ha) and the yield of fresh cherries (in ton/ha). After each processing step, the weight of the remaining product is smaller than the original weight. Following the methodology

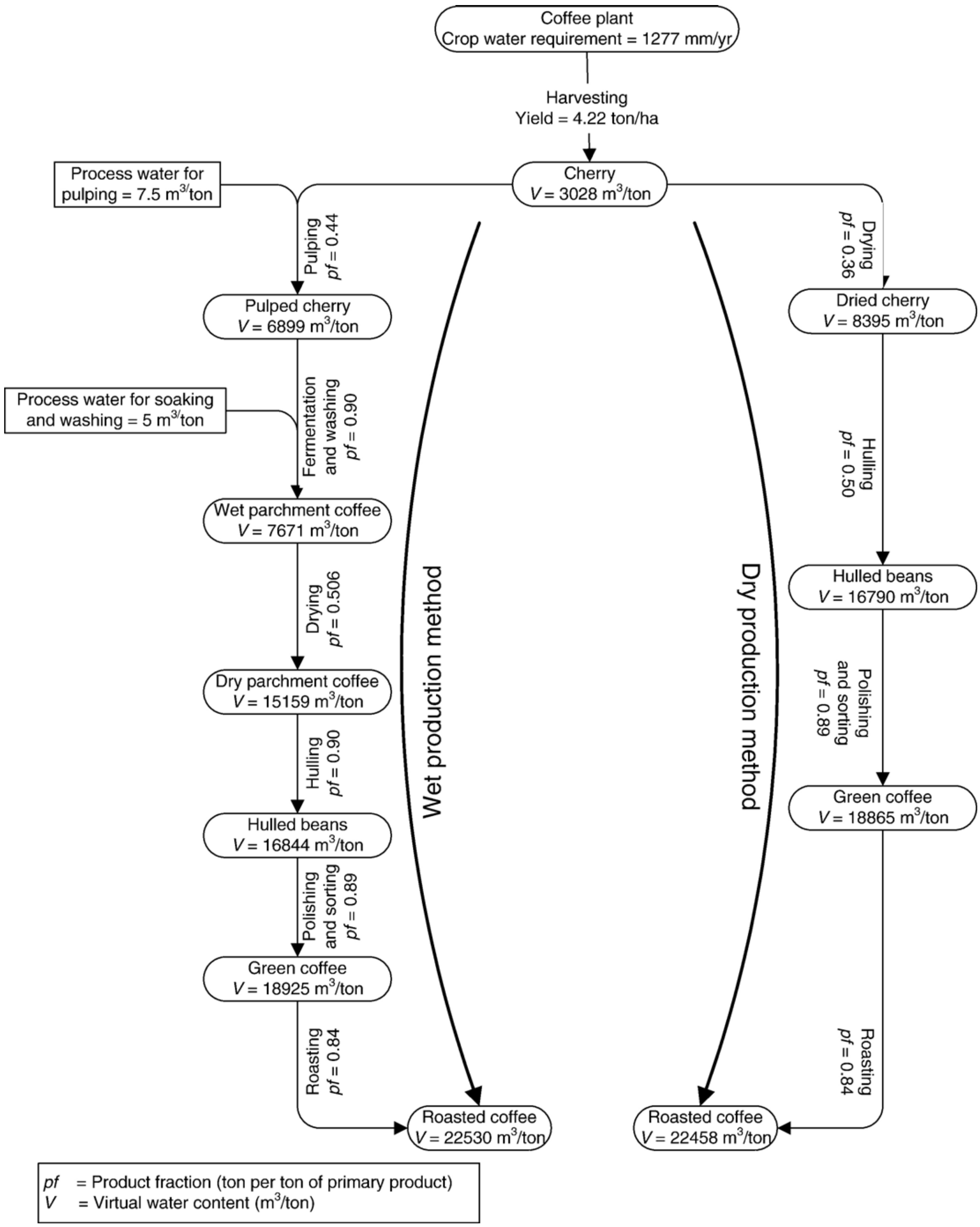

Fig. 1 – Steps in the calculation of the virtual water content of coffee under the different production methods. The numbers are for Brazil.

described by Chapagain and Hoekstra (2004) we define the 'product fraction' (pf) in a certain processing step as the ratio of the weight of the resulting product to the weight of the original product. The virtual water content of the resulting product (expressed in m^3/ton) is larger than the virtual water content of the original product. It can be found by dividing the virtual water content of the original product by the product fraction. If a particular processing step requires water (viz. the processes of pulping, fermentation and washing in the wet production method), the water needed (in m^3 per ton of original product) is added to the initial virtual water content of the original product before translating it into a value for the virtual water content of the resulting product. Fig. 1 shows how the virtual water content of coffee is calculated in its subsequent production stages in both the case of the wet production method and the case of the dry production method. The numbers are based on the example of Brazil. This scheme of calculation is adopted for all other countries with their respective crop water requirement and the yield of fresh cherry. The product fractions and process water requirements are assumed to be constant across different coffee producing countries.

In the case of tea, the virtual water content of fresh leaves is calculated based on the crop water requirement of the tea plant (in m^3/ha) and the yield of fresh leaves (in ton/ha). The

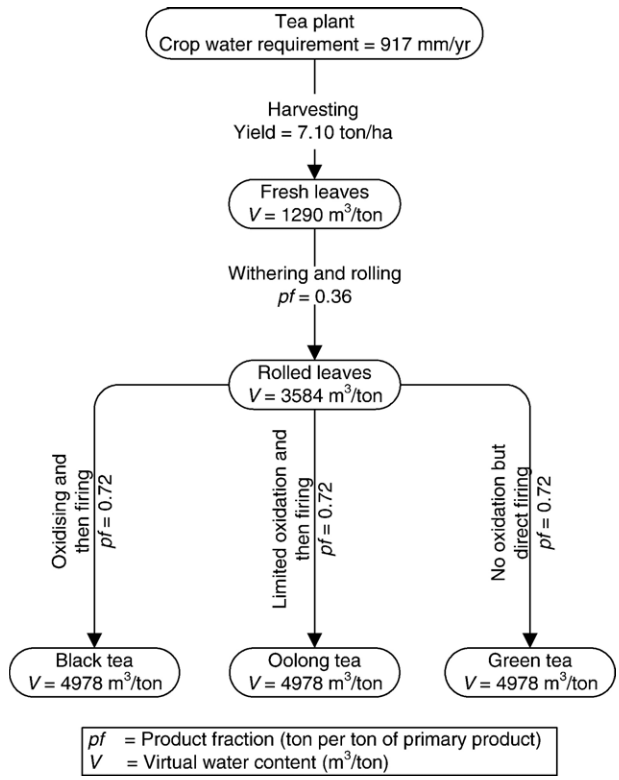

Fig. 2 – Steps in the calculation of the virtual water content of tea. The numbers are for India.

virtual water content at different stages of production is calculated using the same approach followed for coffee. Fig. 2 shows how the virtual water content of tea is calculated in its subsequent production stages in the case of the orthodox production of black tea in India.

The annual crop water requirements of a coffee or tea plant are calculated per country using the CROPWAT model developed by the Food and Agriculture Organization (FAO, 2003a). The crop coefficients for the crops have been taken from Allen et al. (1998). The climate data required as input into the CROPWAT model have been taken from the CLIMWAT database (FAO, 2003b). In the cases where this database contains data for a number of climate stations within a country, the data from the station in the capital has been adopted. It is admitted that this is a crude assumption, because the climate near the capital is not necessarily representative for the climate in the areas in the country where the specific crops are grown, but global data on exact locations of the plantations area are not easily obtainable. Country-specific data on crop production per unit of land (ton/ha) have been obtained from the FAOSTAT database (FAO, 2003c). The figures provided in the database refer to yields in terms of green coffee and 'made tea'. Yields in terms of fresh cherries have been calculated based on the ratio of green coffee weight to fresh cherry weight. Yields in terms of fresh tea-leaves have been calculated based on the ratio of made tea weight to fresh leaves weight.

From fresh cherries to green coffee the weight is reduced to about 16% of the original weight, due to removing pulp and parchment, reduction in moisture content and sorting out of low-quality beans (GTZ, 2002). The weight reduction occurs in steps. In the wet production method, only 44% of the fresh cherry remains after pulping (Bressani, 2003), 90% of the pulped cherry remains after fermentation and washing (Bressani, 2003), 51% of the wet parchment coffee remains after drying (GTZ, 2002) and 80% of the dry parchment coffee remains after hulling, polishing and sorting (GTZ, 2002). In the dry production method, about 36% of the fresh cherry remains after drying (Hicks, 2001), 50% of the dried cherry remains after hulling (Hicks, 2001) and 89% of the hulled beans remains after polishing and sorting. From green coffee to roasted coffee there is another weight reduction, due to reduction in moisture content. The remaining fraction after roasting is generally reported to be 84% of the original green coffee (Hicks, 2001; GTZ, 2002; ICO, 2003).

The wet production method requires water for pulping, fermentation and washing process. The total amount of water needed ranges between 1 and 15 m^3 per ton of cherry (GTZ, 2002). In this study we crudely assume that 7.5 m^3 of water per ton of fresh cherry is needed in the pulping process and that 5 m^3 of water per ton of pulped cherry is needed in the fermentation and washing process (Roast and Post, 2003). If we bring these two numbers into one denominator, this is equivalent to ($7.5+0.44\times5=$) 10 m^3 of water per ton of cherry. We will see later that the overall result of the study, the estimated total water needs for making coffee, are not sensitive to the assumptions made here.

Table 1 shows the calculations for all coffee producing countries from which the Netherlands imports coffee for the wet production method. These countries together are responsible for 84% of the global coffee production. The differences between the two production methods in terms of total water needs are trivial. The virtual water content of green coffee is 17.63 m^3/kg for the wet production method, whereas it is 17.57 m^3/kg for the dry production method (global averages). The water needs for roasted coffee are 20.98 and 20.92 m^3/kg respectively. Most water is needed for growing the coffee plant. In the wet production method, only 0.34% of the total water need refers to process water.

According to Duke (1983), 10 kg of green shoots (containing 75–80% water) produce about 2.5 kg of dried tea. The overall remaining fraction after processing fresh tealeaves into made tea is thus 0.25. The weight reduction occurs in two steps. Withering reduces moisture content up to 70% and drying further reduces it down to about 3% (Twinings, 2003). There is no reduction of weight in the rolling and oxidation processes. In this study, the remaining fraction after withering is taken as 0.72 (ton of withered tea per ton of fresh leaves) and a remaining fraction after firing is taken as 0.36 (ton of black tea per ton of rolled leaves). The different methods of processing fresh tea-leaves into black, green or oolong tea are more or less equal if it comes to the remaining fraction after all (ton of made tea per ton of fresh tealeaves). For that reason, we have not distinguished between different production methods when calculating the virtual water content of tea in the different tea-producing countries. The calculation is made for black tea and assumed to be representative for green tea and oolong tea as well.

Table 2 presents the virtual water content of tea in different production steps for all tea producing countries that export tea

Table 1 – Virtual water content of coffee produced with the wet production method by country

	Production of green coffee (ton/yr)	Yield of green coffee (ton/ha)	Yield of fresh cherry (ton/ha)	Crop water requirement (mm/yr)	Virtual water content (m^3/ton)						
					Fresh cherry	Pulped cherry	Wet parchment coffee	Dry parchment coffee	Hulled beans	Green coffee	Roasted coffee
Brazil	1,370,232	0.68	4.22	1277	3028	6882	7671	15,159	16,844	18,925	22,530
Colombia	689,688	0.74	4.61	893	1939	4406	4920	9723	10,803	12,139	14,451
Indonesia	466,214	0.55	3.41	1455	4268	9699	10,802	21,347	23,719	26,650	31,727
Vietnam	384,220	1.87	11.63	938	807	1833	2061	4074	4526	5086	6054
Mexico	329,297	0.46	2.88	1122	3898	8859	9868	19,502	21,669	24,347	28,985
Guatemala	240,222	0.90	5.60	1338	2388	5428	6055	11,967	13,296	14,940	17,786
Uganda	229,190	0.84	5.25	1440	2741	6230	6947	13,729	15,254	17,139	20,404
Ethiopia	227,078	0.91	5.65	1151	2036	4628	5167	10,212	11,346	12,749	15,177
India	220,200	0.81	5.08	754	1485	3375	3774	7459	8288	9312	11,086
Costa Rica	157,188	1.47	9.14	1227	1342	3051	3414	6748	7497	8424	10,028
Honduras	154,814	0.78	4.87	1483	3044	6919	7712	15,241	16,935	19,028	22,652
El Salvador	138,121	0.85	5.28	1417	2685	6102	6805	13,448	14,942	16,789	19,987
Ecuador	121,476	0.32	1.98	1033	5225	11,875	13219	26,125	29,028	32,616	38,828
Peru	116,177	0.61	3.80	994	2612	5937	6621	13,084	14,538	16,335	19,446
Thailand	75,814	1.12	6.96	1556	2236	5082	5671	11,208	12,453	13,993	16,658
Venezuela	67,802	0.35	2.19	1261	5756	13,082	14,560	28,775	31,972	35,923	42,766
Nicaragua	65,373	0.73	4.55	1661	3649	8294	9240	18,260	20,289	22,797	27,139
Madagascar	63,200	0.33	2.04	1164	5692	12,935	14,397	28,453	31,614	35,521	42,287
Tanzania	44,540	0.38	2.38	1422	5964	13,555	15,085	29,812	33,125	37,219	44,308
Bolivia	22,613	0.94	5.84	1093	1874	4258	4756	9398	10,443	11733	13968
Togo	14,416	0.34	2.12	1409	6643	15,097	16,799	33,199	36,887	41,447	49,341
Sri Lanka	11,133	0.68	4.22	1426	3379	7680	8558	16,913	18,793	21,115	25,137
Panama	10,726	0.41	2.55	1294	5068	11,517	12,822	25,339	28,155	31,634	37,660
Ghana	4909	0.35	2.16	1381	6402	14,549	16,190	31,996	35,552	39,946	47,554
USA	2924	1.24	7.74	938	1212	2754	3085	6097	6774	7611	9061
Average[a]		0.80	4.53	1195	2820	6409	7145	14,121	15,690	17,629	20,987

Period 1995–99.
[a] Country data have been weighted on the basis of their share of green coffee to the global production, which is 6,201,976 ton/yr.

to the Netherlands. These countries together are responsible for 81% of the global tea production. The global average virtual water content of fresh tealeaves is 2.7 m^3/kg. The average virtual water content of made tea is 10.4 m^3/kg. The latter figure has been based on a calculation for black tea, but there would be hardly any difference for green tea or oolong tea, because the overall weight reduction in the case of green tea or oolong tea is similar to the weight reduction when producing black tea. Besides, it is good to note here that black tea takes the largest share in the global production of tea (78%).

Table 2 – Virtual water content of tea by country

Countries	Production (ton/yr)	Yield of made tea (ton/ha)[a]	Yield of fresh tea-leaves (ton/ha)	Crop water requirement of tea plant (mm/yr)	Virtual water content (m^3/ton)		
					Fresh tea-leaves	Withered and rolled leaves	Made tea
Argentina	53,124	1.40	5.39	1286	2387	6630	9208
Bangladesh	51,912	1.08	4.15	1404	3383	9397	13052
Brazil	6753	1.84	7.11	1550	2180	6055	8410
China	649,489	0.73	2.80	1205	4304	11,955	16,604
India	794,180	1.84	7.10	917	1290	3584	4978
Indonesia	160,334	1.43	5.51	1769	3213	8924	12,395
Japan	87,140	1.68	6.47	1165	1802	5004	6950
Mauritius	2206	2.15	8.31	1548	1864	5178	7191
South Africa	10,866	1.66	6.41	1822	2842	7894	10,965
Sri Lanka	269,013	1.41	5.45	1731	3174	8817	12,247
Tanzania	24,140	1.29	4.98	1726	3467	9632	13,377
Turkey	146,756	1.91	7.38	1349	1828	5078	7053
Uganda	20,365	1.12	4.32	1746	4046	11,239	15,610
Weighted mean					2694	7483	10,394

Period: 1995–99.
[a] Source: FAO (2003c).

3. Virtual water flows related to the trade of coffee and tea

The volume of virtual water imported into the Netherlands (in m^3/yr) as a result of coffee or tea import can be found by multiplying the amount of product imported (in ton/yr) by the virtual water content of the product (in m^3/ton). The virtual water content of tea and coffee is taken from the exporting countries. The volume of virtual water exported from the Netherlands is calculated by multiplying the export quantity by the respective average virtual water content of coffee and tea in the Netherlands. The latter is taken as the average virtual water content of the coffee and tea imported into the Netherlands. The difference between the total virtual water import and the total virtual water export is the net virtual water import to the Netherlands, an indicator for the total amount of water needed to have the Dutch drink coffee and tea.

Data on coffee and tea trade have been taken from the database PC-TAS, produced by the United Nations Statistics Division in New York in collaboration with the International Trade Centre in Geneva for the period 1995–99 (ITC, 2002). The total volumes of coffee and tea imported into the Netherlands and the total volumes exported are presented in Table 3. The data are given for four different coffee products: non-decaffeinated non-roasted coffee, decaffeinated non-roasted coffee, non-decaffeinated roasted coffee and decaffeinated roasted coffee. The term 'non-roasted coffee' in PC-TAS refers to what is generally called 'green coffee'. Some of the countries exporting coffee to the Netherlands do not grow coffee themselves. These countries import the coffee from elsewhere in order to further trade it. The UNSD uses the different terminology 'fermented' and 'not fermented' tea for oxidised (black) and non-oxidised (green) tea respectively.

The virtual water import to the Netherlands as a result of coffee import is 2953 million m^3/yr (Table 4). Brazil and Colombia together are responsible for 25% of this import. Other important sources are Guatemala (5%), El Salvador (5%) and Indonesia (4%) as shown in Fig. 3. A large part of the coffee import comes from the non-coffee-producing countries Belgium and Germany (34% in total). The virtual water import to the Netherlands as a result of tea import in the period 1995–99 has been 197 million m^3/yr in average (Table 5). Indonesia is the largest source (contributing 35% of the total import into the Netherlands). Other sources are China (21%), Sri Lanka (14%), Argentina (6%), India (5%), Turkey (3%) and Bangladesh (1%). There is also some import from within Europe: Germany (6%), Switzerland (4%), United Kingdom (2%) and Belgium–Luxemburg (2%). It is difficult to trace back the original source of the coffee and tea imported from the countries that do not produce the crop themselves. For the coffee and tea imported from countries that do not produce the crop themselves, we have taken the global average virtual water content of the product from Tables 1 and 2.

The total import of green coffee over the period 1995–99 amounts to 141×10^3 ton/yr. The import of roasted coffee is 26×10^3 ton/yr. The average virtual water content of coffee imported into the Netherlands is 17.1 m^3 per kg of green coffee and 20.4 m^3 per kg of roasted coffee. These figures are very close to the average global virtual water content of green and roasted coffee respectively. The total import of tea over the period 1995–99 amounts to 17×10^3 ton/yr. The average virtual water content of tea imported into the Netherlands is 11.4 m^3 per kg of made tea. This figure is very close to the global average virtual water content of made tea, which is 10.4 m^3 per kg.

The total virtual water export from the Netherlands as a result of coffee export is 314 million m^3/yr. The largest importers of virtual water from the Netherlands are: Belgium–Luxemburg (23%), United Kingdom (20%), Germany (18%), and France (12%). The total virtual water export from the Netherlands as a result of tea export is 107 million m^3/yr. The largest importers of virtual water from the Netherlands

Table 3 – Coffee and tea import into and export from the Netherlands by product type during the period 1995–99

Product code in PC-TAS	Product	Import (ton/yr)	Export (ton/yr)
090111	Coffee, not roasted, not decaffeinated	135,381	7252
090112	Coffee, not roasted, decaffeinated	5331	731
090121	Coffee, roasted, not decaffeinated	22,020	7229
090122	Coffee, roasted, decaffeinated	3887	1444
090210	Green tea (not fermented) in packages not exceeding 3 kg	225	51
090220	Green tea (not fermented) in packages exceeding 3 kg	936	17
090230	Black tea (fermented) and partly fermented tea in packages not exceeding 3 kg	2580	1346
090240	Black tea (fermented) and partly fermented tea in packages exceeding 3 kg	13,485	7977

Table 4 – Average annual virtual water import to the Netherlands related to coffee import in the period 1995–99

	Virtual water import (10^6 m^3/yr)	Share of total import volume (%)
Belgium–Luxemburg	612	20.7
Brazil	426	14.4
Germany	380	12.9
Colombia	324	11.0
Guatemala	159	5.4
El Salvador	154	5.2
Indonesia	127	4.3
Togo	99	3.3
Tanzania	92	3.1
Mexico	85	2.9
Costa Rica	75	2.6
Nicaragua	73	2.5
Peru	72	2.4
Honduras	48	1.6
India	36	1.2
France	34	1.2
Uganda	32	1.1
Ecuador	19	0.6
Italy	19	0.6
Others	89	2.0
Total	2953	100

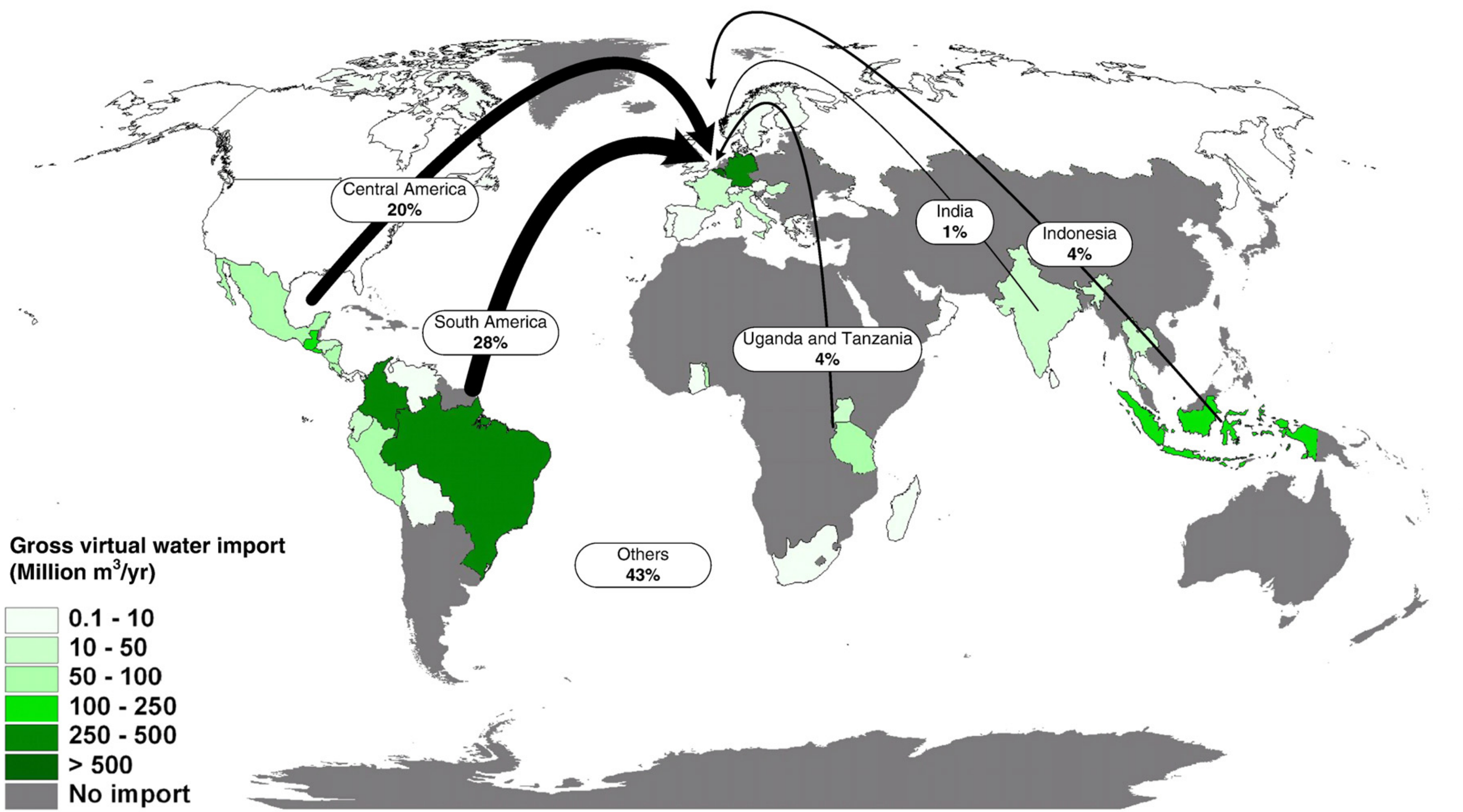

Fig. 3 – Virtual water import to the Netherlands related to coffee imports. The greener the area the more the import to the Netherlands.

Table 5 – Average annual virtual water import to the Netherlands related to tea import in the period 1995–99

	Virtual water import (10^6 m^3/yr)	Share of total import volume (%)
Indonesia	69.2	35.2
China	41.2	21.0
Sri Lanka	28.2	14.4
Argentina	12.0	6.1
Germany	11.5	5.8
India	8.6	4.4
Switzerland–Liecht.	7.2	3.7
Turkey	6.1	3.1
UK	3.5	1.8
Belgium–Luxembourg	3.2	1.6
Bangladesh	1.9	1.0
Tanzania	1.0	0.5
Brazil	0.9	0.5
Others	2.1	1.1
Total	197	100

Table 7 – Average annual virtual water export from the Netherlands related to tea export in the period 1995–99

Origin	Virtual water export (10^6 m^3/yr)	Share of total export volume (%)
Germany	22.2	20.7
UK	18.6	17.3
Russian Federation	16.5	15.4
Switzerland–Liecht	8.1	7.6
USA	6.6	6.2
Italy	4.5	4.2
France	4.3	4.0
Belgium–Luxembourg	2.7	2.5
Saudi Arabia	2.4	2.3
Denmark	2.2	2.1
Canada	1.6	1.5
Austria	1.5	1.4
Finland	1.4	1.3
Others	14.6	13.6
Total	107	100

are: Germany (21%), United Kingdom (17%), the Russian Federation (15%), Switzerland (8%), USA (6%), Italy (4%), France (4%), and Belgium–Luxemburg (3%). Virtual water export from the Netherlands as a result of coffee and tea export are presented in Tables 6 and 7 respectively.

Coffee and tea import are responsible for about 5% of the total gross virtual water import into the Netherlands related to the import of agricultural products (Table 8). The Dutch water footprint related to tea consumption is much smaller than the Dutch water footprint related to coffee consumption, due to the fact that the Dutch consume relatively large amounts of coffee and that tea has much lower virtual water content than coffee.

Table 6 – Average annual virtual water export from the Netherlands related to coffee export in the period 1995–99

	Virtual water import (10^6 m^3/yr)	Share of total import volume (%)
Belgium–Luxemburg	73.5	23.4
UK	61.1	19.5
Germany	55.5	17.7
France	38.7	12.3
Sweden	16.8	5.3
Spain	10.9	3.5
Denmark	9.9	3.1
USA	7.6	2.4
Russian Federation	6.9	2.2
Italy	4.3	1.4
Norway	4.1	1.3
Finland	2.9	0.9
Netherlands–Antil.	2.0	0.6
Austria	1.6	0.5
Lithuania	1.5	0.5
Greece	1.4	0.5
Czech Republic	1.4	0.4
Aruba	1.3	0.4
Portugal	1.2	0.4
Turkey	1.0	0.3
Others	10.3	3.3
Total	314.0	100

4. The water needed to drink a cup of coffee or tea

The quantity of roasted coffee per cup of coffee varies from 5 to 10 g per cup. For the calculation of the virtual water content of a standard cup of coffee in this study, we take 7 g of roasted coffee. Based on the average virtual water content of roasted

Table 8 – Virtual water imports into and exports from the Netherlands related to trade in tea, coffee, crops and livestock products

	Gross import of virtual water (10^6 m^3/yr)	Gross export of virtual water (10^6 m^3/yr)	Net import of virtual water (10^6 m^3/yr)
Related to tea trade (1995–99)	197	107	90
Related to coffee trade (1995–99)	2953	314	2639
Total (coffee and tea)	3150	421	2729
Related to trade in crops and crop products (1997–2001) [a]	48,607	34,529	14,078
Related to trade in livestock and livestock products (1997–2001) [a]	7852	15,146	– 7294
Related to total trade in agricultural products	56,459	49,675	6784

[a] Source: Chapagain and Hoekstra (2004).

Table 9 – Virtual water content of a cup of tea or coffee

		Virtual water content of the dry ingredient (m^3/kg)	One cup of tea or coffee		
			Dry product content (g/cup)	Real water content (l/cup)	Virtual water content (l/cup)
Coffee	—Standard cup of coffee	20.4	7	0.125	140
	—Weak coffee	20.4	5	0.125	100
	—Strong coffee	20.4	10	0.125	200
	—Instant coffee	39.4	2	0.125	80
Tea	—Standard cup of tea	11.4	3	0.250	34
	—Weak tea	11.4	1.5	0.250	17

coffee (20.4 m^3/kg), one cup of coffee requires about 140 l of water in total. A standard cup of coffee is 125 ml, which means that we need more than 1100 drops of water for producing one drop of coffee. For making 1 kg of soluble coffee powder, one needs 2.3 kg of green coffee (Rosenblatt et al., 2003). That means that the virtual water content of instant coffee is about 39,400 m^3/ton. This is much higher than in the case of roasted coffee, but for making one cup of instant coffee one needs a relatively small amount of coffee powder (about 2 g). Surprisingly, the virtual water content of a cup of instant coffee is thus lower than the virtual water content of a cup of normal coffee.

A cup of tea typically requires 1.5 to 3 g of processed tea. We assume here 3 g of processed tea (either black, green or oolong tea) for a cup of normal tea and 1.5 g for 'weak' tea. This is equivalent to 34 l of water per standard cup of tea and 17 l per cup for weak tea. One consumes about 4 times more water if the choice is made for a cup of coffee instead of a cup of tea. With a standard cup of tea of 250 ml, we need about 136 drops of water for producing one drop of tea. The results as presented in Table 9 for the Netherlands are quite representative for the global average, so the figures can be cited in more general terms as well.

5. The water footprint of coffee and tea consumption

With an average of 3 cups of coffee a day per person, the Dutch community has a coffee-related water footprint of 2.6 billion cubic metres of water per year. This is the volume of water appropriated in the coffee-producing countries. The total volume is equivalent to 36% of the annual flow of the Meuse, one of the Dutch rivers. The Dutch people account for 2.4% of the world coffee consumption. All together, the world population requires about 110 billion cubic metres of water per year in order to be able to drink coffee. This is equivalent to 15 times the annual Meuse runoff, or 1.5 times the annual Rhine runoff.

The water footprint of the Dutch tea consumption is 90 million cubic metres per year. Dutch people contribute only 0.28% (7.8×10^3 ton/yr) to the world tea consumption (2.82 million ton/yr). The world population requires about 30 billion cubic metres of water per year in order to be able to drink tea.

The water needed to drink coffee or tea in the Netherlands is actually not Dutch water, because the crops are not produced in the Netherlands. Coffee is produced in Latin America (Brazil, Colombia, Guatemala, El Salvador, Mexico, Costa Rica, Nicaragua, Peru, Honduras), Africa (Togo, Tanzania, Uganda) and Asia (Indonesia, India). The most important sources are Brazil and Colombia. Tea is produced in South East Asia (Indonesia, China, Sri Lanka, India, and Bangladesh) and some other countries in different parts of the world (Argentina, Turkey, Brazil, Tanzania, and South Africa). There are also coffee and tea imports from countries that do not produce coffee or tea themselves, such as Germany and Belgium. They are merely intermediate countries, where tea is just transited or upgraded (e.g. through blending or making brand names to gain higher economic returns).

6. Discussion

The consumption of coffee and tea in the Netherlands has positive impacts on the economies of the producing countries. It generates economic benefits to the producing countries (which are mostly developing countries) with the use of a resource (rainwater) that has relatively low opportunity cost (if compared to ground- and surface water). Although rainwater appropriated for coffee or tea production will often have no alternative use (e.g. production of another crop or natural forest) that will provide higher economic return, the economic value of rainwater should be included in the price of the product. In practice, the economic cost of rainwater is never included in the price of the product. For 1 kg of roasted coffee the price increase could be in the order of 20 dollar cents, assuming that the value of rainwater can be in the order of magnitude of 1 dollar cent per cubic metre (Hoekstra et al., 2001, 2003; Albersen et al., 2003). The exact increase would obviously vary from place to place, subject to local circumstances. A social cost of rainwater use for coffee and tea production, not included in the aforementioned economic cost, is that the use of water for export crops often benefits the richer farmers, which subtracts from the opportunity for smallholder (subsistence) farmers to use water for producing crops for local consumption. It is extremely difficult to express this opportunity cost in monetary units, but this does not take away the fact that this type of social cost does exist. An additional environmental cost of coffee and tea is that coffee and tea plantations often contribute to deforestation, erosion and river pollution (Hoyos, 2005; D'haeze et al., 2005; Adams and Ghaly, in press).

In the cases where irrigation is applied, it is even more important to pass on the economic cost of the water to the consumers of the coffee or tea, because competition over irrigation water is generally more severe than competition over rainwater, which translates into a higher opportunity cost. In practice, the economic cost of irrigation water is usually only partially incorporated in the price of the product. The reason is that irrigation water is generally heavily subsidised (Cosgrove and Rijsberman, 2000).

The volume of water needed to make coffee and tea depends particularly on the climate at the place of production and the yields per hectare that are obtained. The latter partly depends on the climatic conditions, but also on soil conditions and management practice. For the overall water needs, it makes hardly any difference whether coffee is produced with the dry or the wet production process, because the water used in the wet production process is only a very small fraction (0.34%) of the water used to grow the coffee plant. However, this relatively small amount of water can be and actually often is a problem, because this is water to be obtained from surface or groundwater, which is generally scarcer than rainwater (i.e. competition is larger). Besides, the wastewater from the coffee factories is often heavily polluted (GTZ, 2002).

In current practice, coffee as bought by final consumers does neither include in its price the economic, social and environmental costs of water use, nor reveal qualitative information about those costs on its label. It is recommended that the economic, social and environmental significance and impacts of coffee and tea drinking on water footprints be further studied and that practical means be devised to ensure the price of coffee and tea to consumers reflects the full costs of water inputs to cropping and production processes.

REFERENCES

Adams, M., Ghaly, A.E., in press. Maximizing sustainability of the Costa Rican coffee industry. Journal of Cleaner Production doi:10.1016/j.jclepro.2006.08.013.

Albersen, P.J., Houba, H.E.D., Keyzer, M.A., 2003. Pricing a raindrop in a process-based model: general methodology and a case study of the Upper-Zambezi. Physics and Chemistry of the Earth 28, 183–192.

Allen, R.G., Pereira, L.S., Raes, D., Smith, M., 1998. Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements. FAO Irrigation and Drainage Paper, vol. 56. FAO, Rome.

Bressani, R., 2003. *Coffea arabica*: Coffee, Coffee Pulp. AFRIS, 2003. Animal Feed Resources Information System. FAO, Rome.

Chapagain, A.K., Hoekstra, A.Y., 2004. Water Footprints of Nations. Value of Water Research Report Series, vol. 16. UNESCO-IHE, Delft, the Netherlands. Available at www.waterfootprint.org.

Chapagain, A.K., Hoekstra, A.Y., Savenije, H.H.G., Gautam, R., 2006. 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, 186–203.

Cosgrove, W.J., Rijsberman, F.R., 2000. World Water Vision: Making Water Everybody's Business. Earthscan, London.

D'haeze, D., Deckers, J., Raes, D., Phong, T.A., Loi, H.V., 2005. Environmental and socio-economic impacts of institutional reforms on the agricultural sector of Vietnam: Land suitability assessment for Robusta coffee in the Dak Gan region. Agriculture, Ecosystems and Environment 105 (1–2), 59–76.

Duke, J.A., 1983. Handbook of energy crops. Published online: www.hort.purdue.edu/newcrop/duke_energy/Camellia_sinensis.html.

Falkenmark, M., 2003. Freshwater as shared between society and ecosystems: from divided approaches to integrated challenges. Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences 358 (1440), 2037–2049.

FAO, 2003a. CROPWAT Model. Food and Agriculture Organization, Rome.

FAO, 2003b. CLIMWAT Database. Food and Agriculture Organization, Rome.

FAO, 2003c. FAOSTAT Database. Food and Agriculture Organization, Rome.

GTZ, 2002. Post Harvesting Processing. PPP Project, Gesellschaft für Technische Zusammenarbeit, Germany. Available at www.venden.de/postharvestprocessing.htm

Hicks, P.A., 2001. Postharvest processing and quality assurance for speciality/organic coffee products. In: Chapman, K., Subhadrabandhu, S. (Eds.), The first Asian regional round-table on sustainable, organic and speciality coffee production, processing and marketing. 26–28 February 2001, Chiang Mai, Thailand.

Hoekstra, A.Y., Hung, P.Q., 2002. Virtual water trade: a quantification of virtual water flows between nations in relation to international crop trade. Value of Water Research Report Series, vol. 11. UNESCO-IHE, Delft, the Netherlands.

Hoekstra, A.Y., Savenije, H.H.G., Chapagain, A.K., 2001. An integrated approach towards assessing the value of water: a case study on the Zambezi basin. Integrated Assessment 2 (4), 199–208.

Hoekstra, A.Y., Savenije, H.H.G., Chapagain, A.K., 2003. The value of rainfall: upscaling economic benefits to the catchment scale. Proceedings SIWI Seminar 'Towards catchment hydrosolidarity in a world of uncertainties, Stockholm, August 16, 2003'. Report, vol. 18. Stockholm International Water Institute, Stockholm, pp. 63–68.

Hoyos, N., 2005. Spatial modeling of soil erosion potential in a tropical watershed of the Colombian Andes. Catena 63 (1), 85–108.

ICO, 2003. Website of the International Coffee Organisation, London.

ITC, 2002. PC-TAS version 1995–1999, Harmonized System, CD-ROM. International Trade Centre, Geneva.

Rees, W.E., 1992. Ecological footprints and appropriated carrying capacity: what urban economics leaves out. Environment and Urbanization 4 (2), 121–130.

Rosenblatt, L., Meyer, J., Beckmann, E., 2003. Koffie: Geschiedenis, teelt, veredeling, met 60 heerlijke koffierecepten. Fontaine Uitgevers, Abcoude, the Netherlands.

Roast, Post, 2003. From Tree to Cup, Processing. The Roast and Post Coffee Company, UK.

Twinings, 2003. Black Tea Manufacture. R Twining and Company Ltd, London.

UNESCO, 2003. Water for People, Water for Life: The United Nations World Water Development Report, UNESCO Publishing, Paris/Berghahn Books, Oxford.

UNESCO, 2006. Water, A Shared Responsibility: The United Nations World Water Development Report 2, UNESCO Publishing, Paris/Berghahn Books, Oxford.

Wackernagel, M., Rees, W., 1996. Our Ecological Footprint: Reducing Human Impact on the Earth. New Society Publishers, Gabriola Island, B.C., Canada.