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Analysis

Sustainability of national consumption from a water resources perspective: The case study for France

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ABSTRACT

It has become increasingly evident that local water depletion and pollution are often closely tied to the structure of the global economy. It has been estimated that 20% of the water consumption and pollution in the world relates to the production of export goods. This study analyzes how French water resources are allocated over various purposes, and examines impacts of French production in local water resources. In addition, it analyzes the water dependency of French consumption and the sustainability of imports. The basins of the Loire, Seine, Garonne, and Escaut have been identified as priority basins where maize and industrial production are the dominant factors for the blue water scarcity. About 47% of the water footprint of French consumption is related to imported agricultural products. Cotton, sugar cane and rice are the three major crops that are identified as critical products in a number of severely water-scarce river basins: The basins of the Aral Sea and the Indus, Ganges, Guadalquivir, Guadiana, Tigris & Euphrates, Ebro, Mississippi and Murray rivers. The study shows that the analysis of the external water footprint of a nation is necessary to get a complete picture of the relation between national consumption and the use of water resources.

1. Introduction

In recent years, it has become evident that local water depletion and pollution are tied to the structure of the global economy (Hoekstra and Chapagain, 2007). It has been estimated that about twenty percent of the water consumption and pollution in the world relates to the production of export goods (Hoekstra and Mekonnen, 2012). International trade in commodities implies long-distance transfers of water in virtual form, where virtual water is understood as the volume of water that has been used to produce a commodity and that is thus virtually embedded in it (Chapagain and Hoekstra, 2008). Knowledge about the virtual-water flows entering and leaving a country can cast a new light on the actual water scarcity of a country. For developing a responsible national water policy, it is also relevant to consider the linkages between consumed goods in a country and impacts on freshwater systems where the goods are produced.

The water footprint is an indicator of freshwater use that looks not only at direct water use of a consumer or producer, but also at the indirect water use. The water footprint can be regarded as a comprehensive indicator of freshwater resources appropriation, next to the traditional and restricted measure of water withdrawal (Hoekstra et al., 2011).

The objective of this study is to carry out a water footprint assessment for France from both a production and consumption perspective. The aim of the assessment from the production perspective is to analyze how French water resources are allocated over various purposes, and examine where the water footprint of production within France exceeds local environmental flow requirements and ambient water quality standards. Additionally, the aim is to quantify which volumes of French water resources are allocated for making products for export and to assess the impact related to this water footprint for export. The assessment from the consumption perspective focuses on the analysis of the external water footprint of French consumption, to get a complete picture of how national consumption translates to water use, not only in France, but also abroad, and to assess French dependency on external water resources and the sustainability of imports. The sustainability is addressed from environmental perspective; social and economic aspects are not taken into account.

The study starts with a quantification and mapping of the water footprint of the agricultural and industrial sectors and of domestic water supply within France. Next, virtual water imports into France and virtual water exports leaving France are quantified, by traded commodity. Subsequently, the internal and external water footprints of French consumption are analyzed. Finally, it has been analyzed which components of the French blue water footprints of production and consumption contribute to blue water scarcity in specific river basins and which products are responsible herein.

From a methodological point of view, this study improves upon the previous country-specific water footprint studies in three ways, following the global study by Mekonnen and Hoekstra (2011b). First, the water footprints of production and consumption are mapped at a high level of spatial detail. Second, the analysis explicitly

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includes green, blue and gray water footprints. Finally, we make a substantial step beyond quantifying and mapping the country's water footprint of production and consumption by analyzing how different components in the water footprint may contribute to blue water scarcity in different river basins and identifying which products are behind those contributions.

2. Method and Data

2.1. Water Footprint Accounting

This study follows the methodology and terminology of water footprint assessment as described in the Water Footprint Assessment Manual (Hoekstra et al., 2011). A water footprint has three components: green, blue and gray. The blue water footprint refers to consumption of blue water resources (surface and ground water). The green water footprint is the volume of green water (rainwater) consumed, which is particularly relevant in crop production. The gray water footprint is an indicator of the degree of freshwater pollution and is defined as the volume of freshwater that is required to assimilate the load of pollutants based on existing ambient water quality standards.

The water footprint of national production is the total freshwater volume consumed or polluted within the territory of the nation. This includes water use for making products consumed domestically but also water use for making export products. It is different from the 'water footprint of national consumption', which refers to the total amount of water that is used to produce the goods and services consumed by the inhabitants of the nation. This refers to both water use within the nation and water use outside the territory of the nation, but is restricted to the water use behind the products consumed within the nation. The water footprint of national consumption thus includes an internal and external component. The internal water footprint of national consumption is defined as the use of domestic water resources to produce goods and services consumed by the national population. It is the sum of the water footprint within the nation minus the volume of virtual-water export to other nations insofar as related to the export of products produced with domestic water resources. The external water footprint of national consumption is defined as the volume of water resources used in other nations to produce goods and services consumed by the population in the nation considered. It is equal to the virtual-water import into the nation minus the volume of virtual-water export to other nations because of re-export of imported products.

The water footprint of crops and derived crop products produced in France or elsewhere were obtained from Mekonnen and Hoekstra (2010a, 2011a), who estimated the global water footprint of crop production with a crop water use model at a 5 by 5 arc minute spatial resolution. The water footprint of animal products that are produced in France was taken from Mekonnen and Hoekstra (2010b, 2012). The data related to the water footprint of production and consumption in France and the virtual water flows to and from France were taken from Mekonnen and Hoekstra (2011b). In all cases, data refer to the period 1996–2005.

2.2. Identifying Priority Basins and Products

For the blue water footprint of French production and consumption, some additional analysis was carried out in order to identify river basins of concern. After we quantified and mapped the blue water footprints of French production and consumption, we estimated which parts of both water footprints are situated in river basins with moderate to severe water scarcity during part of the year. Monthly blue water scarcity values for the major river basins around the world were taken from a recent global water scarcity study (Hoekstra and Mekonnen, 2011; Hoekstra et al., 2012). The blue water scarcity values in that study were calculated by taking the aggregated blue water footprint of production per basin and per month over the blue water availability in that basin and month. The latter was taken as natural runoff in the basin minus a presumptive standard for the environmental flow requirement in the basin. They classified blue water scarcity values into four levels:

- low blue water scarcity (<100%): the blue water footprint is lower than 20% of natural runoff and does not exceed blue water availability
- moderate blue water scarcity (100–150%): the blue water footprint is between 20 and 30% of natural runoff
- significant blue water scarcity (150–200%): the blue water footprint is between 30 and 40% of natural runoff
- severe water scarcity (>200%): the monthly blue water footprint exceeds 40% of natural runoff.

The following three criteria have been used to identify priority basins regarding the various components of the blue water footprint of French production or consumption: level of water scarcity over the year in the basin where the water footprint component is located, the size of the blue water footprint of French production or consumption located in the basin (agricultural and industrial products separately), and the significance of the contribution of a specific product to the total blue water footprint in the basin in the scarce month.

A specific river basin is identified as a 'priority basin' related to France's water footprint of production or consumption of agricultural/industrial products if three conditions are fulfilled: (a) the river basin experiences moderate, significant or severe water scarcity in any specified period of the year; (b) the French blue water footprint of production or consumption of agricultural/industrial products located in that basin is at least 1% of total blue water footprint of production or consumption of agricultural products; and (c) the contribution of any specific agricultural commodity to the total blue water footprint in that specific basin in the period of scarcity is significant (more than 5%). In addition, a river basin is also identified as a priority basin if the following two conditions are met: (a) the water scarcity in the river basin is severe during any month of the year; and (b) the contribution of any specific agricultural commodity/industrial product produced or consumed in France to the total blue water footprint in that specific basin in the period of scarcity is very significant (more than 20%). Fig. 1 shows how basins are identified as a "priority basin".

3. Water Footprint Calculations

3.1. Water Footprint of Production

The total water footprint of national production in France is 90 Gm^3/year for the period 1996–2005, which is 1% of the total water footprint of production in the world (Hoekstra and Mekonnen, 2012). The largest part of this water footprint is green (76%), followed by gray (18%) and blue (6%) (Table 1). Crop production constitutes the largest share (82%) in the water footprint of national production in France, followed by industrial activities (8%), grazing (6%), domestic water supply (3%) and livestock production (drinking and service water) (1%). Among the crops, cereals contribute 47% to the total water footprint. Fodder crops (15%), oil seed crops (9%) and fruits and nuts (6%) are the other major crop groups with a significant share in the total water footprint. Crop production contributes 50% to the total *blue* water footprint within France. The shares of industrial production, animal water supply and domestic water supply in the blue water footprint are 26, 14 and 11% respectively. In France, the gray water footprint is largely due to crop and industrial production.

The spatial distributions of the green, blue and gray water footprints of national production in France are shown in Fig. 2. Center region has the largest water footprint with 9.6 Gm^3/year (12% of the total). Other

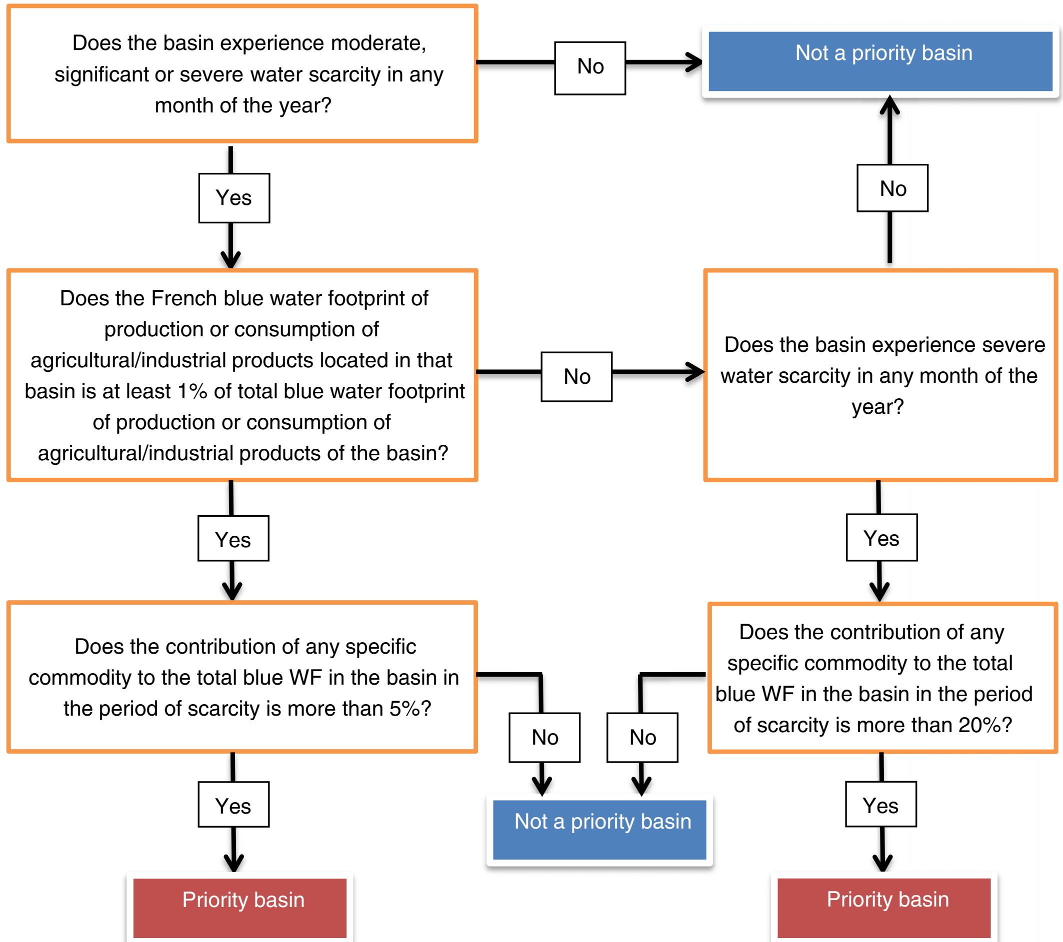

Fig. 1. Identification of priority basin.

regions with a significant share are Midi-Pyrenees (7.6 Gm^3/year), Poitou-Charentes (6.7 Gm^3/year), Champagne-Ardenne (5.5 Gm^3/year), Aquitaine (5.4 Gm^3/year), Pays de la Loire (5.3 Gm^3/year), Picardie (5 Gm^3/year), Bourgogne (4.7 Gm^3/year), and Rhone-Alpes (4.2 Gm^3/year). The largest *blue* water footprint in France is in Midi-Pyrenees (where 14% of the blue water footprint within France is located). The largest *gray* water footprint in France is in Ile-de-France (where 10% of the gray water footprint within France is located).

The water footprint of agricultural production (crop production, grazing, and livestock water supply) in the period 1996–2005 was 80 Gm^3/year, which is 89% of the total water footprint in France. Wheat (29%), fodder crops (18%), maize (14%), barley (9%), rapeseed (7%), grapes (5%), sunflower (4%) and sugar beet (2%) are together responsible for 88% of the total agricultural water footprint.

Fig. 3 shows the contribution of different crops to the green, blue and gray water footprints of total crop production in France. Maize production has the largest blue water footprint and equals to the 50% of the total. Other crops with a significant share in the blue water footprint are fodder crops (6%), potato (4%), soybean (3%), rice (3%), and apples (2%). The green water footprint is mainly due to wheat production (34%), followed by fodder crops (19%), maize (10%), barley (9%), rapeseed (7%), grapes (6%), and sunflower (3%). The largest contribution to the gray water footprint comes from maize production (30%), followed by barley (18%), fodder crops (14%), sunflower (11%), rapeseed (9%), potato (4%) and sugar beet (3%).

The water footprint of industrial production in France in the period 1996–2005 was 7.1 Gm^3/year. This footprint is dominated by the gray component (5.6 Gm^3/year), which represents the pollution (BOD and COD are taken into account) due to industrial production. The water footprint of industrial production is concentrated in the Seine (26%), Rhone (15%), Loire (13%), Rhine (7%) and Garonne (6%) basins.

The water footprint of domestic water supply in France in the period 1996–2005 was 2.8 Gm^3/year. The majority of it is gray water footprint

Table 1
The water footprint of national production in France (Gm^3/year) by major category.

Water footprint of crop production			Water footprint of grazing	Water footprint of animal water supply	Water footprint of industrial production		Water footprint of domestic water supply		Total water footprint		
Green	Blue	Gray	Green	Blue	Blue	Gray	Blue	Gray	Green	Blue	Gray
62.7	2.85	8.02	5.7	0.778	1.49	5.65	0.628	2.22	68.37	5.74	15.89

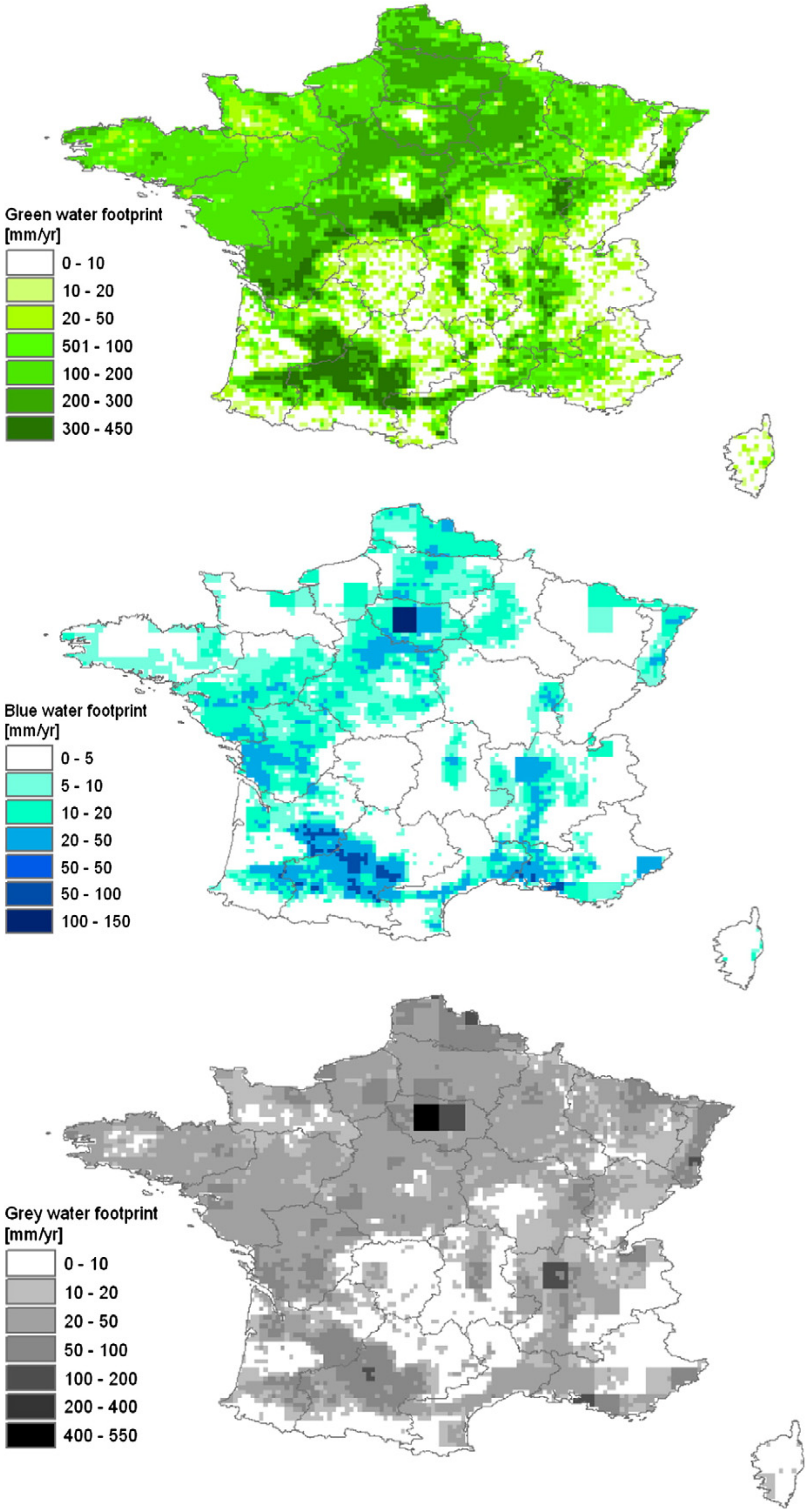

Fig. 2. Spatial distribution of the green, blue and gray water footprint of production in France. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this contribution.)

(78%). This water footprint is large where population concentrations are high and located mainly in Ile-de-France, Rhone-Alpes and Provence-Alpes-Cote d'Azur. From a river basin point of view: the Seine, Rhone, Loire and Rhine basins, where most of the French population lives, have the largest water footprint related to domestic water supply.

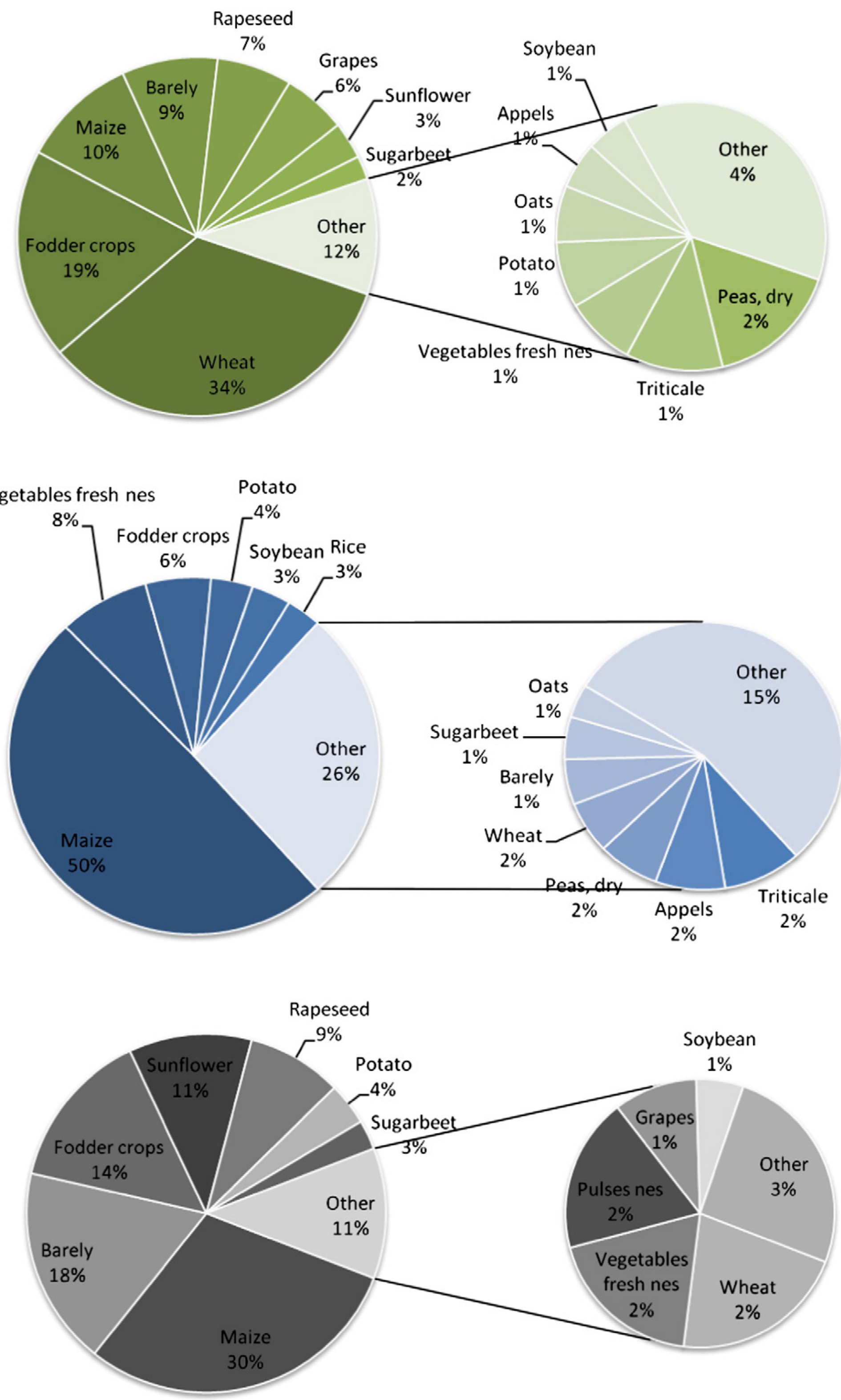

Fig. 3. The contribution of different crops to the green, blue and gray water footprint of total crop production in France. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this contribution.)

3.2. Virtual Water Flows

The total virtual water import to France in the period 1996–2005 was 78.3 Gm^3/year. About 73% of the virtual water imports relates to imported crops and crop products, 15% to imported industrial products and 12% to imported animal products (Table 2). The largest share (22%) of the total virtual water import relates to the import of cotton and its derived products. Fig. 4 shows the contribution of different products to the virtual water import, distinguishing between green, blue and gray virtual water imports.

Table 2
Virtual water import and export to/from France by product category (Gm^3/year).

	Crop products			Animal products			Industrial products		Total		
	Green	Blue	Gray	Green	Blue	Gray	Blue	Gray	Green	Blue	Gray
Import	45.1	8.6	3.8	7.6	0.9	0.6	1.0	10.7	52.7	10.5	15.1
Export	35.9	4.9	4.4	10.1	1.5	0.8	1.0	6.7	46.0	7.4	12.0

The green water footprint of imported products is 52.7 Gm^3/year and is 67% of total virtual water import. Cotton products have the largest green water footprint among the imported products, accountable for 18% of the total green virtual water import. Soybean products (17%), animal products (14%), cocoa products (13%) and coffee products (11%) are other products with a significant share in the green virtual water import. The blue water footprint of imported products in France is 10.5 Gm^3/year. Approximately 56% of this footprint is due to cotton products. Animal and industrial products also have significant shares in blue virtual water imports (9% each). The gray water footprint of imported products is 15.1 Gm^3/year. Industrial products give the largest contribution to this gray water footprint (71%), followed by cotton products (13%) and animal products (4%).

The majority of the virtual water imports to France originate from Brazil (10%), Belgium (9%), Spain (7%), Germany (7%), Italy (6%) and India (5%). Spain, Belgium, Morocco, Italy, India, Uzbekistan, and Turkey are the largest blue virtual water exporters to France, accounting for 55% of the blue virtual water import. The gray component of virtual water import is mainly from China (10%), Germany (10%), Russia (10%), Italy (7%), Belgium (7%), the USA (7%), Spain (5%) and India (4%).

The blue water footprint related to the total of imported cotton products is mainly located in Uzbekistan, Turkey, India, Tajikistan, Turkmenistan and China. The blue water footprint related to imported animal products mainly lies in Spain, Belgium, the Netherlands, Germany and Italy. Most of the gray water footprint related to the import of industrial products lies in Russia (14%), China (11%), Germany (10%) and the USA (7%).

The total virtual water export from France in the period 1996–2005 was 65.5 Gm^3/year (Table 2). Since virtual water imports were larger than virtual water exports, France is a net virtual water importer. The virtual water export is dominated by export of crop products (69%) and followed by animal products (19%) and industrial products (12%). The largest part of the virtual water export concerns green water (70%). The blue and gray virtual water exports contribute 11 and 18% of total virtual water exports respectively.

The largest virtual water flows leaving France go to the EU countries like Belgium (16%), Italy (13%), Germany (11%), Spain (8%), the United Kingdom (7%), the Netherlands (7%) and also to Algeria (3%) and Libya (3%). Fig. 5 shows the virtual water exports by product category. This figure only shows virtual water exports related to domestically made products. Animal and wheat products together are responsible for 54% of the green virtual water flows from France. Barley, maize, rapeseed, sunflower and grape products are other major commodities with a large share in green virtual water exports. Blue virtual water exports from France are mainly due to the export of animal products (39%), industrial products (26%) and maize products (17%). The largest gray virtual water export is due to the export of industrial products (61% of the total) and is followed by maize, animal and barley products.

3.3. Water Footprint of Consumption

The total water footprint of consumption in France is 106 Gm^3/year over the period 1996–2005. The green component is the largest and is equal to 76% of total water footprint of consumption. Blue and gray water footprints of national consumption are 8 and 17% of the total. About 53% of the water footprint of French national consumption is internal and 47% is external (Table 3). This means that nearly half of the water resources consumed or polluted to make all products consumed by French citizens are water resources outside the country.

The largest fraction (87%) in the total water footprint of French consumers relates to the consumption of agricultural products. Consumption of industrial products and domestic water supply contributes 10% and 3% to the total water footprint of consumption, respectively (Table 3). The internal water footprint of French consumption is mainly because of the consumption of agricultural products, followed by industrial products and domestic water supply. The external water footprint is largely due to the import of agricultural products for domestic consumption, and for a smaller part due to the import of industrial products. The ratio of external to total water footprint of consumption is higher for industrial products (62%) than for agricultural products (47%). Furthermore, the ratio of external to total water footprint is significantly higher for the blue water footprint (64%) than for the green water footprint (46%) or the gray water footprint (47%). For agricultural products, even 77% of the total blue water footprint of consumption is external.

With a contribution of 34%, meat consumption is the largest contributor to the total water footprint of French consumption (Fig. 6). Industrial products (10%), coffee, tea and cocoa (9%), and milk (9%) are other large contributors. The consumption of cereals and sugar contributes 5% and 4% to the total water footprint of consumption, respectively. Rubber, fruits, wine & beer, and domestic water supply each have a 3% share in the total water footprint of consumption. As can be seen from Fig. 7, meat, coffee-tea-cocoa, milk, vegetable oils and cereals have the largest shares in the total green water footprint of French national consumption (40, 12, 10, 7 and 6% respectively). The blue water footprint is also dominated by meat consumption (23%). The other sectors with a large share in the total blue water footprint are consumption of industrial products (18%), fruits (8%), milk (8%) and domestic water supply (8%). The gray water footprint of consumption is mainly due to the consumption of industrial products (54%), followed by domestic water supply (13%), meat (12%) and milk (5%).

When we compare the external water footprint of France to virtual water imports (Section 3.2), we see that some part of the virtual water imports to France is not consumed domestically. Around 35% 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. A typical example of such processing is related to cotton and cocoa products. Crops are imported from Asia and Latin America to be used as an input to textile and cocoa industries. When we compare the internal water footprint of French consumption to the water footprint of production within France, we see that the latter is much bigger. About 60% of the total water footprint of production in France is for domestic consumption. The rest of the water footprint in the country is for the production of export commodities.

The geographic distribution of the water footprint of consumption by French citizens is shown in Fig. 8. More than 50% of the external water footprint of French consumption comes from Brazil, Belgium, Spain, Germany, Italy, India and the Netherlands. The geographic spreading of the external water footprint related to the consumption of agricultural and industrial products is different from each other. The external agricultural water footprint is mainly from Brazil, Belgium, India, Spain, and Germany, while the external industrial water footprint is more concentrated in China, Russia, Germany and the USA.

4. Priority Basins and Products

4.1. Water Footprint of Production

As described in Section 3.1, the blue water footprint of France is dominated by crop production and followed by industry and domestic

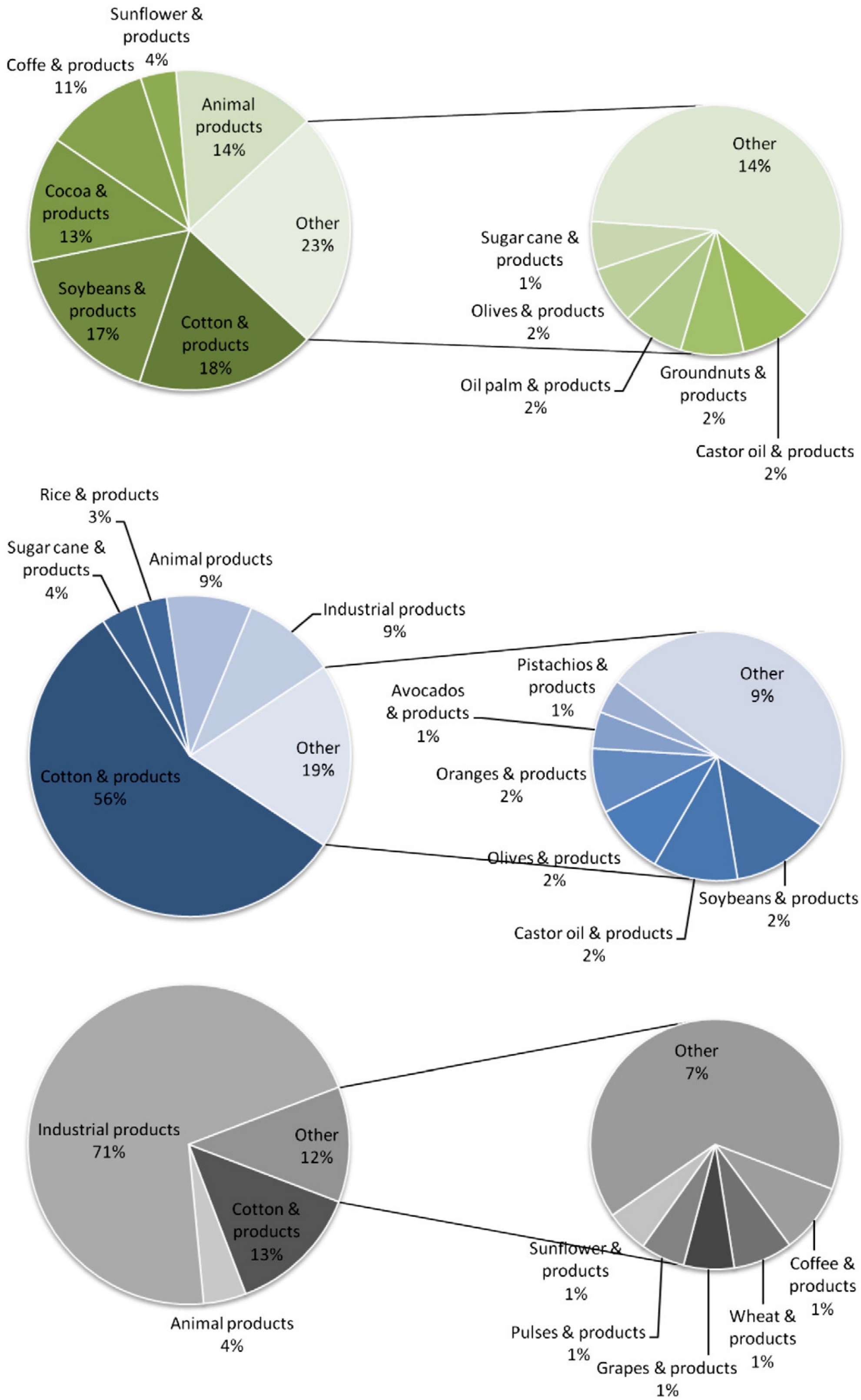

Fig. 4. The green, blue and gray virtual water import to France by product group. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this contribution.)

water supply. The blue water footprint is mainly located in the Loire, Seine, Garonne, Rhone, Rhine and Escaut river basins. Four of these basins – the Loire, Seine, Garonne and Escaut – experience moderate to severe water scarcity at least one month a year. Table 4 shows, for each of these four basins, the months in which the moderate to severe water scarcity occurs and the products that dominate the water footprint in these months. The Loire, Seine and Garonne basins have the largest shares in the blue water footprint of production in France, 15%

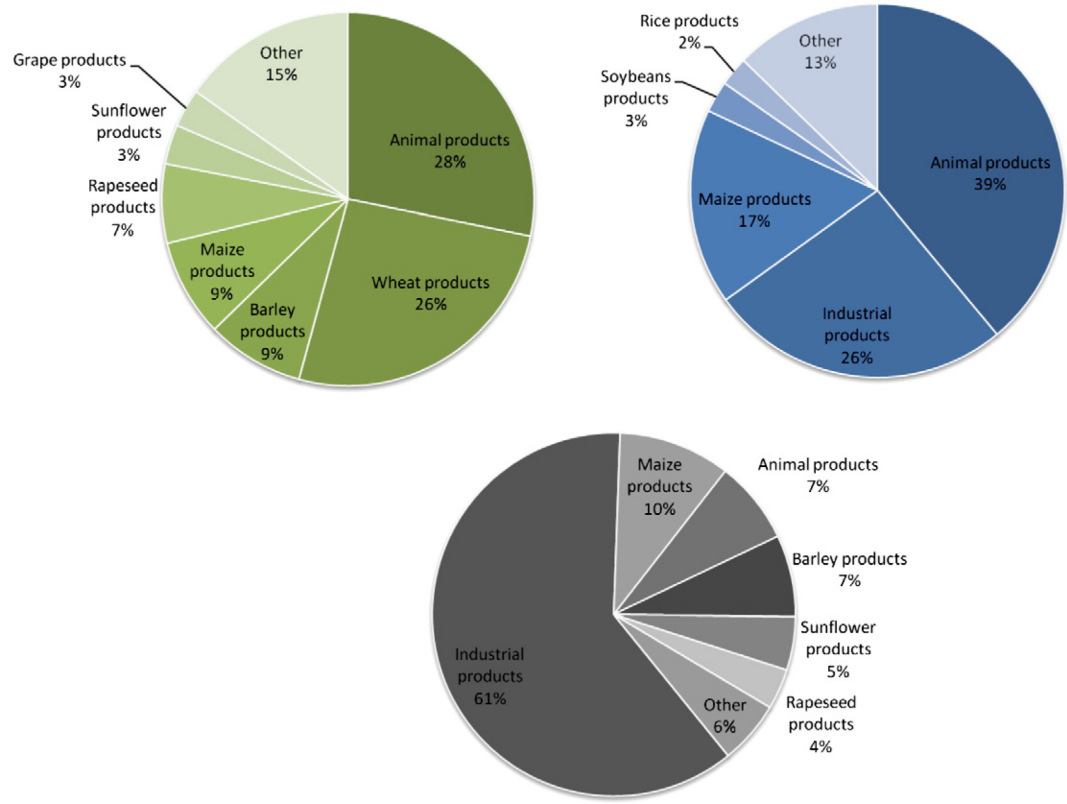

Fig. 5. Green, blue and gray virtual water export from France by product group. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this contribution.)

each. The blue water footprint in the Escaut basin is much smaller, but the area of this basin is also much smaller than for the other three basins.

The Loire river basin experiences significant water scarcity in August and September. The main activities contributing to the blue water footprint in this basin are maize and industrial production. The Loire basin is considered an important farming area, producing two thirds of the livestock and half of the cereal produced in France. The banks of the river offer a habitat for a rich biodiversity. The river is a refuge for European beavers, otters, and crested newts, and a migration route for fish such as Atlantic salmon. The decrease in water levels in the river during the summer period has a negative effect on the biodiversity located in the banks of the river (UNEP, 2004).

The Seine and Escaut river basins experience water scarcity from July to October. The blue water footprint during this period in these basins is mainly because of industrial production, domestic water supply, and maize and potato production. The Seine River passes through Paris; the high level of urbanization and industrialization has a major impact on the water quality in the basin. Pollution is due to industrial and domestic wastewater, but also intensive agriculture. Agricultural production has a big impact on water quality because it favors intensive farming techniques and spring crops, which leave the soil bare for long periods of the year and increase the chemical load in the rivers by leaching and draining. This has a harmful effect on both the environment and other water uses. Improving water quality is still the major concern of the basin, where non-point source pollution from farming and urban areas is still a major problem, as nitrate, pesticide and heavy metal concentrations continue to increase (UNEP, 2004).

The Garonne faces moderate to severe water scarcity in the period from July to September. The production of maize is the dominant factor behind the blue water scarcity in this basin. Soybean and fodder are two other products that contribute significantly to the blue water footprint in the basin. The Garonne is the most important river of south-western France and the main water source for five major cities, including Bordeaux. The Bordeaux region is known for its industrial activities and is well known for the quality of its vineyards. The region especially experiences water shortages during summertime (UNESCO, 2006; AEAG, 2011). The Garonne is an important breeding area for sturgeon and for the migration of Atlantic salmon. Its estuary, in particular, is a very important site for fish and bird migrations. The water quality is worsening with wastewater from the city of Bordeaux, causing high levels of nitrogen and phosphorous

Table 3
The water footprint of French consumption (Gm^3/year).

Water footprint of consumption of agricultural products						Water footprint of consumption of industrial products				Water footprint of domestic water supply		Total water footprint of consumption					
Internal			External			Internal		External				Internal			External		
Green	Blue	Gray	Green	Blue	Gray	Blue	Gray	Blue	Gray	Blue	Gray	Green	Blue	Gray	Green	Blue	Gray
43.7	1.375	3.75	36.74	4.58	2.08	0.876	3.32	0.58	6.277	0.63	2.22	43.7	2.88	9.3	36.74	5.16	8.36

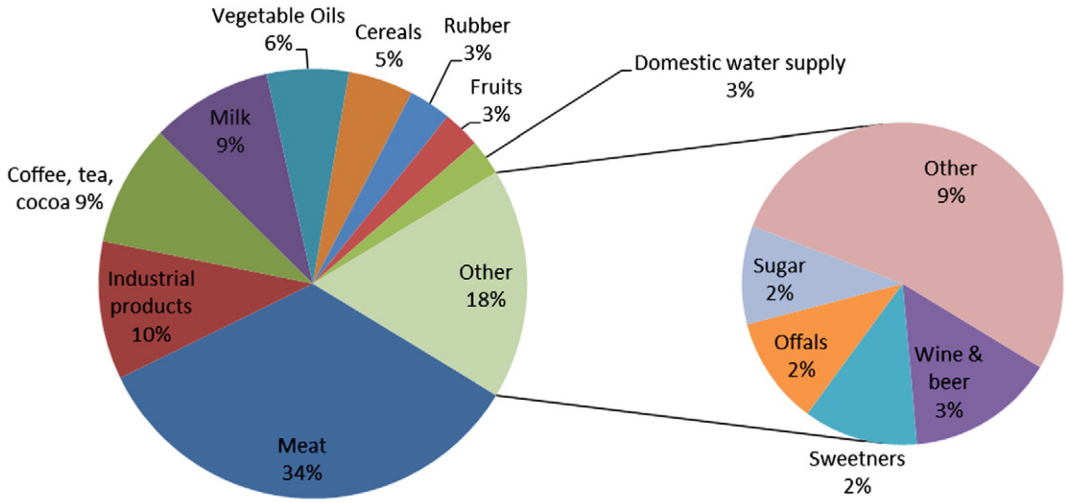

Fig. 6. The total water footprint of French consumption shown by consumption category.

concentrations downstream of Bordeaux. One tributary of the Garonne, the Dropt, is particularly sensitive to eutrophication (Devault et al., 2007; UNEP, 2004). The pollution of a few heavy metals is observed in the Garonne due to industrial activities, especially mining in the basin. This contamination is considered as critical because of the sensitivity of the marine ecosystems located at the downstream (Grousset et al., 1999).

A significant portion of the blue water footprint of production in France is for production of export commodities. Around 60% of the agricultural blue water footprint and 40% of the industrial blue water footprint of production are not for producing commodities for internal consumption but for production of export goods. Therefore, some of the impacts of the water footprint of production in French river basins are due to consumption happening elsewhere in the world but not in France.

4.2. Water Footprint of Consumption

The blue water footprint of French consumption is partly within France and partly outside. In many of the basins where part of the water footprint of French consumption is located, water scarcity is beyond hundred percent during part of the year.

4.2.1. Agricultural Products

We will focus first on the water footprint of French consumption of agricultural products. Table 5 presents the river basins across the globe where there is a significant blue water footprint related to French consumption of agricultural products and where there is moderate, significant or severe water scarcity during part of the year. A 'significant' blue water footprint in a basin means here that at least 1% of the blue water footprint of French consumption of agricultural products is located in this basin. The table also shows a list of river basins where less than 1% of the blue water footprint of French consumption of agricultural products is located. In these basins, water scarcity is severe during part of the year (or even the full year) and the contribution of one or more specific agricultural commodities to the total blue water footprint in the basin in the period of severe scarcity is very significant (more than 20%). Although France imports the products, which contributes water scarcity significantly, in relative small amounts (less than 1% of the blue water footprint of French consumption of agricultural products is located in those basins), these products are obviously contributing to very unsustainable conditions. Table 5 shows, per basin, the number of months per year that the basin faces moderate, significant or severe water scarcity, and priority products per basin. These priority products are the products that contribute significantly to the basin's blue water scarcity and are imported by France. The basins listed in Table 5 are shown on the world map in Fig. 9.

The Aral Sea basin is identified as one of the most important priority basins, since 6% of the blue water footprint of French consumption of agricultural products is located there. The basin experiences one month of moderate water scarcity (June) and four months of severe water scarcity (July to October). Cotton production is the dominant factor in the blue water scarcity of the basin (more than 50%). Next in line of the priority basins are the four French river basins that were already identified in the previous section as well: the Garonne, Loire, Escaut and Seine basins. The blue water footprints within those basins lead to moderate to severe water scarcity during parts of the year. For an important part, the blue water footprints of production in these basins relate to producing for the domestic market. A sixth priority basin is the Indus basin, in which 4% of the blue water footprint of French consumption of agricultural products is located. The basin faces severe water scarcity during eight months of the year. The blue water footprint in the Indus basin is mainly due to wheat, cotton, rice and sugar cane production. However, wheat is not one of the products that France imports from Pakistan, thus it is not a product of major concern for French consumers.

The Ganges, Krishna, Godavari, Cauvery, Tapti and Penner basins are river basins in India that are identified as priority basins. All these basins experience severe water scarcity during most of the year. Rice and sugar cane production are the major reasons of blue water scarcity in these basins. The Guadalquivir is Spanish and Guadiana, Douro and Tagus are Spanish–Portuguese river basins in which the blue water footprint of French consumption is significant. Sugar beet, maize, grapes, citrus and sunflower are the products that are imported by France and contribute largely to the blue water footprint in these basins.

As can be seen from Table 5, mainly eight agricultural products of concern are identified in 36 different priority basins: cotton, rice, sugar cane, sugar beet, soybean, maize and grape. Among them, cotton, sugar cane and rice are the three major crops. They have the largest share in the external blue water footprint of French consumption and are identified as products of concern in most of the priority basins. Therefore, we examined the impacts of these three products in some of the identified priority basins in detail.

Cotton is probably the most important product if it comes to the contribution of French consumers to blue water scarcity. French cotton consumption relates to blue water scarcity in a number of basins throughout the world: the Aral Sea basin (Uzbekistan), the Indus (Pakistan), the Guadalquivir (Spain), the Tigris & Euphrates (originating in Turkey and ending in Iraq), the Mississippi (USA), the Yongding

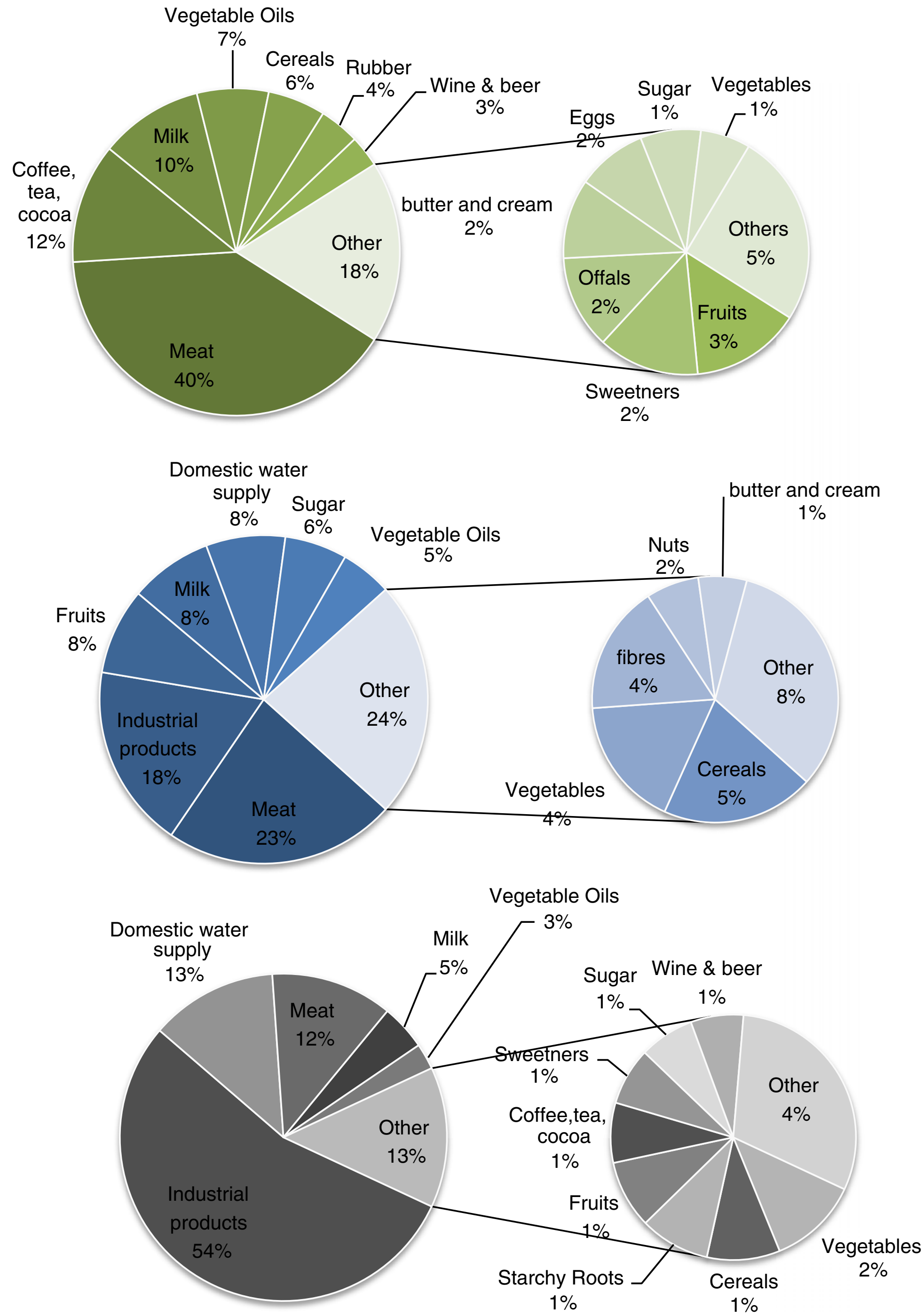

Fig. 7. The green, blue and gray water footprint of French consumption per consumption category. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this contribution.)

He (China), the Limpopo (South Africa), the San Joaquin (USA), the Tapti (India), and the Murray (Australia). The Aral Sea ecosystem has been experiencing sudden and severe ecosystem damage due to excessive water abstractions from the inflowing rivers to irrigate cotton fields and other export crops. This unsustainable use of water has environmental consequences, including fisheries loss, water and soil contamination, and dangerous levels of polluted airborne sediments. The impacts of extensive irrigation in the Aral Sea basin have extended far beyond the decline of the sea water level: millions of people lost access to the lake's water, fish, reed beds, and transport functions. Additionally, environmental and ecological problems associated with extensive water use for irrigation negatively affected human health and economic development in the region (Cai et al., 2003; Glantz, 1999; Micklin, 1988). Another well-documented case is the Murray basin in Australia, where water levels have declined significantly, particularly due to water abstractions for irrigation. Much of its aquatic life, including native fish, is now declining, rare or endangered (Chartres and Williams, 2006).

Sugar cane is the second product if it comes to the contribution of French consumers to blue water scarcity in the world. Sugar cane consumed in France contributes to water scarcity in the following priority basins: the Indus (Pakistan), the Ganges (India), the Krishna (India),

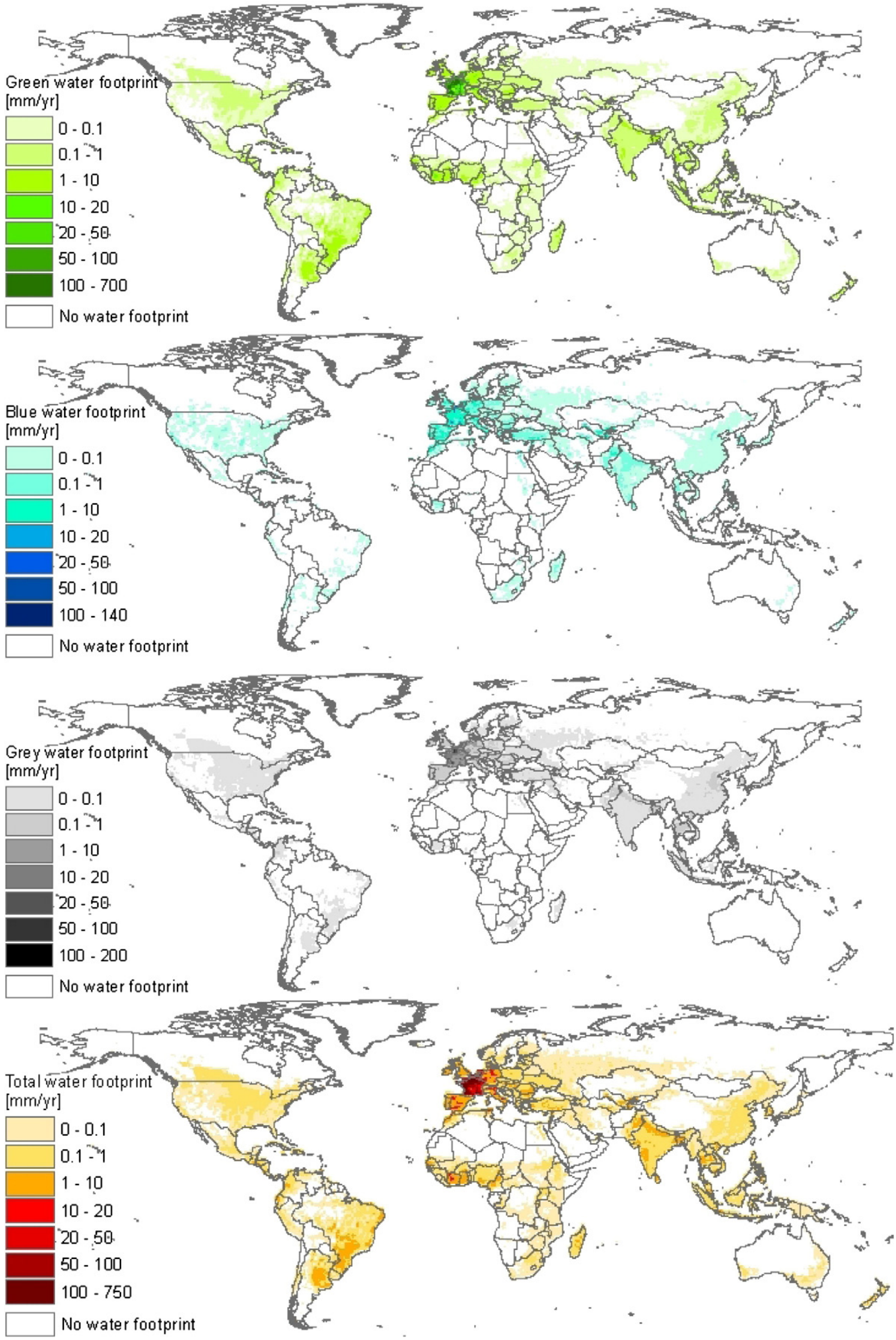

Fig. 8. The global water footprint of consumption by the inhabitants of France (period 1996–2005).

Table 4
Priority basins regarding the blue water footprint of production in France.

River basin	Month	Level of scarcity	Products with significant contribution to the blue water footprint in the basin (% of contribution)
Loire	August	Significant	Maize (58%), industrial production (6%)
	September	Significant	Maize (45%), industrial production (10%)
Seine	July	Moderate	Industrial production (28%), maize (18%), domestic water supply (12%), potato (11%)
	August	Severe	Maize (38%), industrial production (21%), domestic water supply (9%), potato (%7), sugar beet (%6)
	September	Severe	Industrial production (28%), maize (27%), domestic water supply (12%)
	October	Moderate	Industrial production (5%), domestic (24%)
Garonne	July	Moderate	Maize (54%), soybean (1%), fodder (5%)
	August	Significant	Maize (59%), soybean (7%)
	September	Severe	Maize (69%), soybean (8%)
Escaut	July	Significant	Industrial production (61%), domestic water supply (17%), potato (10%)
	August	Severe	Industrial production (57%), domestic water supply (16%), maize (10%), potato (8%)
	September	Severe	Industrial production (70%), domestic water supply (20%)
	October	Severe	Industrial production (77%), domestic water supply (22%)

the Godavari (India), the Chao Phraya (Thailand), the Bandama (Côte d'Ivoire), the Cauvery (India), the Limpopo (South Africa), the Sassandra (Côte d'Ivoire), the Comoe (Côte d'Ivoire), the Tapti (India), the Murray (Australia), the Incomati (South Africa) and the Doring (South Africa). The freshwater reaching to Indus delta has significantly decreased (90%) as a result of over-usage of water sources in the Indus basin. Sugar cane is one of the main water consuming agricultural products in the basin. The decrease in freshwater flow to the Indus delta has negative impacts on the ecosystems and biodiversity of the delta (such as decrease of mangrove forestlands and danger of extinction of the Blind River Dolphin). Additionally, excessive water usage in sugar cane cultivation areas has led to salinity problems (WWF, 2004). Moreover, untreated wastewater discharge from sugar mills causes depletion of available oxygen in water sources, which threatens fish and other aquatic life (Akbar and Khwaja, 2006). India is also facing environmental problems due to sugar cane cultivation. In the Indian state of Maharashtra, sugar cane irrigation is 60% of the total irrigation supply, which causes substantial groundwater withdrawals (WWF, 2004). India's largest river, the Ganges, experiences severe water scarcity. Sugar cane is one of the major crops cultivated in the area and

Table 5
Priority basins regarding the blue water footprint of French consumption of agricultural products.

River basin	Percentage of the blue water footprint of French consumption of agricultural products located in this basin	Number of months per year that a basin faces moderate, significant or severe water scarcity			Major contributing products
		Moderate	Significant	Severe	
Aral Sea basin	6.4	1	0	4	Cotton
Garonne	5.4	1	1	1	Maize, soybean, animal products
Escaut (Schelde)	4.5	0	1	3	Maize, potato
Loire	4.4	0	2	0	Maize
Indus	3.9	1	3	8	Cotton, rice, sugar cane
Guadalquivir	3.0	1	0	6	Cotton, sun flower, rice, sugar beet
Seine	2.2	2	0	2	Maize, potato, sugar beet
Ganges	2.2	0	2	5	Rice, sugar cane
Guadiana	1.8	1	0	6	Grapes, sunflower, citrus
Tigris & Euphrates	1.6	0	1	5	Cotton, rice
Po	1.6	2	0	0	Rice, animal products
Ebro	1.4	0	0	3	Maize
Sebou	1.4	1	1	5	Sugar beet
Douro	1.3	2	0	3	Maize, sugar beet
Tagus	1.0	1	0	4	Grapes, maize, animal products
Mississippi	0.60	2	0	2	Maize, soybean, rice, cotton
Krishna	0.45	1	1	7	Rice, sugar cane
Godavari	0.31	2	0	5	Rice, sugar cane
Kizilirmak	0.27	1	2	2	Sugar beet
Chao Phraya	0.26	2	1	4	Rice, sugar cane
Sakarya	0.25	0	1	5	Sugar beet
Bandama	0.21	0	0	2	Sugar cane, animal products
Cauvery	0.19	3	1	8	Rice, sugar cane
Yongding He	0.12	0	0	12	Cotton, soybean
Limpopo	0.11	2	0	5	Sugar cane, cotton
Sacramento	0.10	1	0	5	Rice
San Joaquin	0.10	1	0	7	Cotton, maize
Sassandra	0.08	0	0	2	Sugar cane
Comoe	0.08	0	0	2	Sugar cane
Tapti	0.07	2	1	5	Cotton, sugar cane
Murray	0.06	2	0	6	Sugar cane, cotton, rice
Penner	0.04	1	2	9	Rice
Incomati	0.03	1	0	3	Sugar cane
Tugela	0.02	2	0	3	Grape, animal products
Doring	0.01	0	1	7	Sugar cane, grapes
Nueces	0.01	0	0	12	Maize

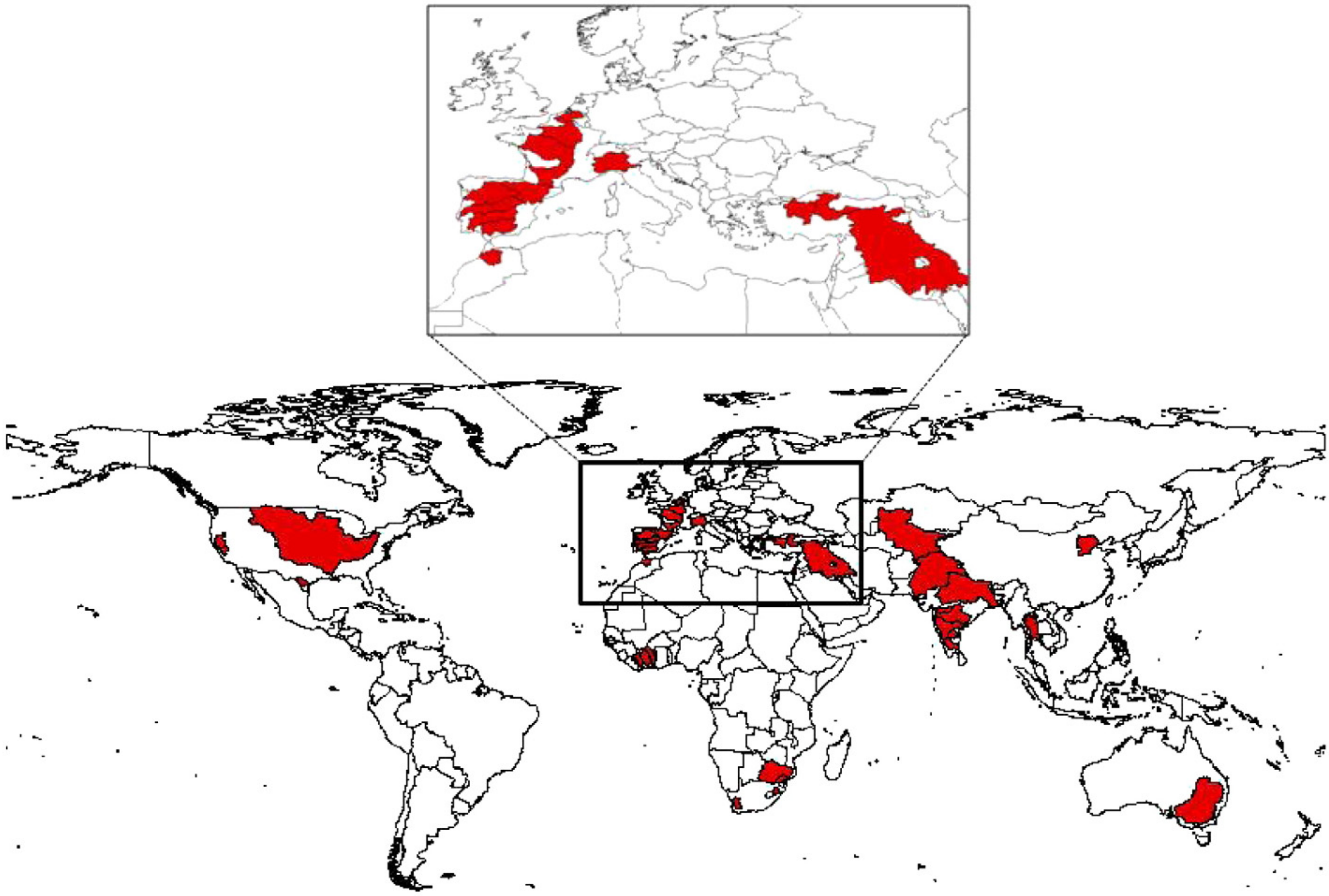

Fig. 9. The river basins in the world in which the production of agricultural products for French consumption contributes to moderate, significant or severe blue water scarcity.

deteriorates the water scarcity. Another problem resulting from sugar cane cultivation and sugar processing activity in India is the pollution of surface and groundwater resources (gray water footprint) (Solomon, 2005).

Rice has the third largest share in the external blue water footprint of French consumption. In the following priority basins, rice is identified as one of the major products contributing to blue water scarcity: the basins of the Indus (Pakistan), Guadalquivir (Spain), Ganges (India), Tigris & Euphrates (Turkey to Iraq), Mississippi (USA), Krishna (India), Godavari (India), Chao Phraya (Thailand), Cauvery (India), Sacramento (USA) and Murray (Australia). The Guadalquivir is Spain's second longest river. Its natural environment is one of the most varied in Europe. Its middle reaches flow through a populous fertile region where its water is used extensively for irrigation. The lower course of the Guadalquivir is used for rice cultivation. In recent years, mass tourism and intensive irrigated agriculture in the region are causing over-exploitation of regional aquifers, which damages the ecosystem of the region (UNEP, 2004). The Guadalquivir marshes are negatively affected due to agricultural activities. The Guadalquivir is classified as one of the rivers in Europe mostly polluted due to non-point source emissions from agricultural activities (nitrate and phosphate) (Albiac and Dinar, 2008).

4.2.2. Industrial Products

There are two river basins that face moderate to severe water scarcity during part of the year and where more than 1% of the blue water footprint of French consumption of industrial products is located: the Seine and Escaut basins (Table 6). There are seven river basins where this contribution is smaller, but that can be classified as priority basin for another reason. These river basins are the basins of the Volga, St. Lawrence, Ob, Wisla, Don, Yongding He and Colorado. In these basins, water scarcity is severe during part of the year or even the full year, as in the case of the Yongding He (Table 6). Although France imports industrial products from these basins in relative small amounts (less than 1% of the blue water footprint of French consumption of industrial products is located in those basins), these products contribute to very unsustainable conditions because industrial products contribute more than 20% to the total blue water footprint in the basin in the period of severe scarcity.

Table 6
Priority basins regarding the blue water footprint of French consumption of industrial products.

River basin	Percentage of the blue water footprint of French consumption of industrial products located in this basin	Number of months per year that a basin faces moderate, significant or severe water scarcity		
		Moderate	Significant	Severe
Seine	5.5	2	0	2
Escaut (Schelde)	1.5	0	1	3
Volga	0.43	0	0	1
St. Lawrence	0.31	0	0	1
Ob	0.23	1	0	1
Wisla	0.14	0	0	1
Don	0.10	0	2	2
Yongding He	0.09	0	0	12
Colorado (Caribbean Sea)	0.01	1	0	6

Industrial products contribute to pollution as well. France's industrial gray water footprint is located mainly in the Seine, Loire, Rhone, Escaut, Garonne, Volga, Mississippi, Po, St. Lawrence, Tigris & Euphrates, Ob, Huang He (Yellow River) and Yangtze basins. China's longest river, the Yangtze, has been severely polluted. The surface water pollution in the river includes industrial and domestic sewage, animal manures, chemical fertilizers from farmlands, and polluted sediments. The Yellow River in China is known for pollution problems as well. According to Chinese government estimates, around two-thirds of the Yellow River's water is too polluted to drink. Around 30% of fish species in the river are believed to have become extinct and the river's fish catch has declined by 40% (Fu et al., 2004).

5. Discussion and Conclusion

Linking specific consumer products in a country to water problems elsewhere is still uncommon in governmental thinking about water policy. Making this link visible can help in setting priorities in either national or international context with respect to the most effective measures to reduce water footprints in the basins where most needed. The study addresses questions like: where and when water footprints are largest, where and when they contribute most to local water scarcity and which specific products contribute most to water footprints and water scarcity? By making the links between specific consumer products and water problems visible, the study suggests that consumer product policy can be part of a water policy. This can be in terms of labeling, product transparency, tariffs or in terms of taxes and quotas. However, this study does not examine alternatives for policy responses that can be applied in practice. In addition, it is not realistic to implement such policy tools just based on the results of this study or only considering water perspective. These mechanisms are complex and based on many other factors: labor, land, economy and other socio-economic elements. Water represents just one consideration in a government's agricultural, energy, industrial and trade policy and strategy. French government may want to explore the need of institutional mechanisms to ensure that the imported products made in sustainable way where they are produced. However, it is difficult for one individual country to implement policy tools to influence sustainability of imported products. Knowledge about the virtual-water flows entering and leaving a country can cast a completely new light on the actual water scarcity of a country. This study shows how a political debate on this topic could be informed by relevant knowledge on how different products contribute to water scarcity.

Even though the study applies higher spatial and temporal resolutions than previous national water footprint studies, there are still limitations regarding the spatial and temporal detail, which primarily relate to lacking crop and irrigation data on even higher resolutions and to the problem of tracing supply chains and trade flows. One limitation in the study is that the origin of virtual water imports and the external water footprint of consumption have not been traced further than the first tier trade partners. If a product is imported from a country, we assume that the product has been produced in that country and we take the water footprint of the imported product accordingly. Another limitation related to trade data is that the origins of imported commodities are available on country level and not specified as per river basin or in even more geographic detail. In this study, we assumed that an imported product originates from the various river basins within the country proportionally to the production of that product in the various basins. However, in reality exported commodity can be produced somewhere else inside the exporting country. Therefore, this link should be taken into account cautiously and a more elaborative study should be done before identifying or implementing any policy responses.

Another limitation in the study pertains to the problem of distinguishing between different industrial products. Different crop and animal products have been considered separately, but industrial commodities are treated as one product group. In future studies it would be worth trying to analyze different industrial sectors and commodities separately; currently, the major challenge still is the lack of water consumption and pollution data per industrial sector and the complexity of supply chains for many industrial commodities.

In this study, identification of priority river basins and priority products from the perspective of water resource use has been done primarily on the basis of data on the levels of blue water scarcity through the year on a river basin level. More precise results would be obtained if we could use water scarcity data on a finer spatial resolution level, for example at the level of sub-catchments. Especially for identifying hotspots within large river basins, this would be very helpful. Furthermore, by looking at 'blue water scarcity' from an environmental point of view, we may have neglected social issues of water conflict. For obtaining a more complete overview of potential critical basins and products, it would be helpful to look at other indicators than environmental water scarcity alone. It should further be noted that the blue water scarcity estimates used in this study (from Hoekstra and Mekonnen, 2011; Hoekstra et al., 2012) excluded the evaporation from storage reservoirs and the effect of inter-basin water transfers. This may result in an underestimation of blue water scarcity in basins with significant evaporation from large reservoirs and export of water to another basin and an overestimation of water scarcity in basins that receive significant volumes of water from another basin. The water scarcity estimates also exclude storage effects of large dams, which means that water scarcity may have been underestimated in periods of the year in which water is being stored and overestimated in periods of the year in which the water is being released. Finally, we used a number of criteria to identify priority basins, with certain thresholds (like the threshold of 'at least 1% of the total blue water footprint should be located in the basin') that can be considered as subjective choices. Obviously, changing thresholds will lead to longer or shorter lists of 'priority basins'.

The national water footprint of France presented in this study provides a high-level view of its dependence on the world's freshwater resources. Different components of French water footprint have different sets of impacts explicitly linked to time and location from where the footprint originates. One of the most important conclusions of this study is that a shift in focus to the local watershed level from where the footprint is originated is necessary to understand the true impact of a country's water footprint. Additionally, it is essential to look at both how much water is used and when it is used in order to assess the impacts of local water consumption on local ecosystems.

Despite the limitations of the study, it has been proven that it is possible to make a rough sketch of where different economic sectors contribute to scarcity within the country and of which consumer goods contribute to water scarcity in specific river basins outside the country. The study shows that analysis of the external water footprint of a nation is necessary to get a picture of how national consumption depends on foreign water resources.

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