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ANALYSIS

The water footprints of Morocco and the Netherlands: Global water use as a result of domestic consumption of agricultural commodities

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ABSTRACT

The volume of international trade in agricultural commodities is increasing faster than the global volume of production, which is an indicator of growing international dependencies in the area of food supply. Although less obvious, it also implies growing international dependencies in the field of water supply. By importing food, countries also import water in virtual form. The aim of the paper is to assess the water footprints of Morocco, a semi-arid/arid country, and the Netherlands, a humid country. The water footprint of a country is defined as the volume of water used for the production of the goods and services consumed by the inhabitants of the country. The internal water footprint is the volume of water used from domestic water resources; the external water footprint is the volume of water used in other countries to produce goods and services imported and consumed by the inhabitants of the country. The study shows that both Morocco and the Netherlands import more water in virtual form (in the form of water-intensive agricultural commodities) than they export, which makes them dependent on water resources elsewhere in the world. The water footprint calculations show that Morocco depends for 14% on water resources outside its own borders, while the Netherlands depend on foreign water resources for 95%. It is shown that international trade can result in global water saving when a water-intensive commodity is traded from an area where it is produced with high water productivity to an area with lower water productivity. If Morocco had to domestically produce the products that are now imported from the Netherlands, it would require 780 million m^3/year. However, the imported products from the Netherlands were actually produced with only 140 million m^3/year, which implies a global water saving of 640 million m^3/year.

1. Introduction

Throughout the world freshwater resources have become scarcer during the past decades, due to an increase in population and economic activity and a subsequent increase in water appropriation (Postel et al., 1996; Shiklomanov, 2000; Vörösmarty et al., 2000; Vörösmarty and Sahagian, 2000). In most countries the increase in water use was largely related to increased production of agricultural products for domestic consumption. However, also water use for producing export commodities has become significant in various countries. In the period 1997–2001 about 15% of the global water use in

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agriculture was not for producing commodities for domestic consumption but for export (Chapagain and Hoekstra, 2004). In some specific countries (e.g. Australia, Canada, Argentina), the agricultural water use for export is even larger than for domestic consumption. These countries export water in 'virtual' form, that is in the form of agricultural commodities. The virtual water content of a commodity is the volume of water used to produce the commodity, measured at the place where the commodity was actually produced. The other side of this phenomenon is that some countries import agricultural commodities instead of producing them domestically, thus importing water in virtual form and saving domestic water resources. Examples are most countries in the Middle East, North Africa and Europe, but also South Africa, Mexico and Japan (Chapagain and Hoekstra, 2004).

The aim of this paper is to assess the water footprints of Morocco, a semi-arid/arid country, and the Netherlands, a humid country. The water footprint of a nation is the total annual volume of freshwater that is used to produce the goods and services consumed by the inhabitants of the nation. Generally, a part of the footprint of a nation falls inside the country (internal water footprint) and another part presses on other countries in the world (external water footprint). For that purpose we quantify for both countries incoming and outgoing virtual water fluxes. In addition, we estimate water savings or losses that result from the international virtual water trade. As period of analysis we have taken 1997–2001, because this was the most recent five-year period for which all necessary data could be obtained. The study is limited to agricultural commodities, since they are responsible for the major part of global water use (Postel et al., 1996).

2. Terminology and methodology

The paper makes use of a number of novel concepts such as the 'virtual water content' of a commodity, the 'water footprint' of a nation and the 'water saving' as a result of international trade. The virtual water concept was introduced by Allan (1998a,b) when he studied the possibility of importing virtual water (as opposed to real water) as a partial solution to problems of water scarcity in the Middle East. Allan elaborated the idea of using virtual water import (coming along with food imports) as a tool to release the pressure on the scarcely available domestic water resources. Virtual water import thus becomes an alternative water source, next to endogenous water sources. Imported virtual water has therefore also been called 'exogenous water' (Haddadin, 2003). Global virtual water flows were first calculated by Hoekstra and Hung (2002, 2005), Zimmer and Renault (2003), Oki et al. (2003), Chapagain and Hoekstra (2004, in press) and De Fraiture et al. (2004).

The water footprint concept has been introduced by Hoekstra and Hung (2002) when looking for an indicator that could map the impact of consumption of people on the global water resources. The concept was subsequently elaborated by Chapagain and Hoekstra (2004). The water footprint shows water use related to consumption within a nation, while the traditional indicator of water use (i.e. total water withdrawal for the various sectors of economy) shows water use in relation to production within a nation. The water footprint does not only show water use within the country considered, but also the water use outside the country borders. It refers to all forms of water use that contribute to the production of goods and services consumed by the inhabitants of a certain country. The water footprint of the Dutch community for example also refers to the use of water for rice production in Thailand (insofar the rice is exported to the Netherlands for consumption over there). Both internal and external water footprints have three components: the blue, green and grey water footprint. The terms blue and green water refer to the source of the water used (Falkenmark, 2003). The source of green water is rain, while the source of blue water is ground or surface water. In more precise terms, green water use in agriculture is the volume of evaporated rainwater (evaporation through either transpiration by the plant or direct evaporation from the soil or leave surface). Blue water use refers to evaporated irrigation water. The grey water footprint component refers to the volume of water required to dilute pollutants to such an extent that concentrations are reduced to agreed maximum acceptable levels (Chapagain et al., 2006b). In the current paper we have quantified only the green and blue water footprint components.

The idea of actively promoting the import of virtual water in water-scarce countries is based on the idea that a nation can save its domestic water resources by importing a water-intensive product rather than produce it domestically. Import of virtual water thus leads to a 'national water saving'. In addition to this, Oki and Kanae (2004) introduced the idea of a 'global water saving'. International trade can save water globally when a water-intensive commodity is traded from an area where it is produced with high water productivity (low water input per unit of output) to an area with lower water productivity (high water input per unit of output). On the other hand, of course, there can be a 'global water loss' if a water-intensive commodity is traded from an area with low to an area with high water productivity. Recent estimates of global water savings and losses as a result of international trade have been made by De Fraiture et al. (2004), Chapagain et al. (2006a) and Yang et al. (2006).

Since the International Expert Meeting on Virtual Water Trade, held in Delft, the Netherlands, in December 2002 (Hoekstra, 2003) and the special session on Virtual Water Trade and Geopolitics during the Third World Water Forum in Japan, March 2003, the interest in the concepts of virtual water, water footprints and global water saving has strongly increased (Merrett, 2003; Allan, 2003; Wichelns, 2004; Ramirez-Vallejo and Rogers, 2004; WWC, 2004; Oki and Kanae, 2004, 2006; Kumar and Singh, 2005; Chapagain et al., 2006a,b; Ma et al., 2006; Yang et al., 2006; Hoekstra and Chapagain, 2007). The most comprehensive and elaborated framework for analysis currently available is the one developed by the authors of this paper (Chapagain and Hoekstra, 2004, in press; Chapagain et al., 2006a, b; Hoekstra and Chapagain, 2007). In this paper we use this framework without modifications.

A nation's water footprint (m^3/year) has two components: the internal and the external water footprint. The internal water footprint (W_i) is defined as the use of domestic water resources to produce the goods consumed by inhabitants of the country. It is the sum of the total water volume used from the domestic water resources in the national economy *minus* the volume of virtual water export to other countries insofar related to export of domestically produced products:

$$W_i = NWU - VWE_{dom} \quad (1)$$

Here, NWU is the national water use and VWE_{dom} the virtual water export to other countries insofar related to export of domestically produced products. In this study we only take into account water use for producing agricultural commodities. Water use for crop growth is taken equal to the evaporative water demand of the crops grown. In this way we include both effective rainfall (the portion of the total precipitation which is retained by the soil and used for crop production) and the part of irrigation water used effectively for crop production. We do not include irrigation losses, assuming that they largely return to the resource base and thus can be reused.

The external water footprint of a country (W_e) is defined as the annual volume of water resources used in other countries to produce the goods consumed by the inhabitants of the country concerned. It is equal to the so-called virtual water import into the country *minus* the volume of virtual water exported to other countries as a result of re-export of imported products.

$$W_e = VWI - VWE_{re-export} \quad (2)$$

Both the internal and the external water footprint include the use of *blue water* (originating from ground and surface water) and the use of *green water* (soil moisture originating from rain).

International virtual water flows (m^3/year) have been calculated by multiplying commodity trade flows (ton/year) by their associated virtual water content (m^3/ton). The commodity trade flows have been taken from the PC-TAS database (Personal Computer Trade Analysis System) available from the International Trade Center (ITC, 2004). This database covers trade data from 146 reporting countries disaggregated by product and partner countries. We have carried out calculations for 285 crop products and 123 livestock products. In this study, 'ton' refers to a metric ton of 1000 kg.

The virtual water content of a commodity (m^3/ton) is defined as the volume of water used to produce the commodity in the exporting country. The virtual water content of primary crops has been calculated as the crop water requirement at field level (m^3/ha) divided by the crop yield (ton/ha). We have made our calculations on the basis of crop water requirements instead of *actual* water use for the practical reason that worldwide crop-specific irrigation data are not available, so that we have optimistically assumed that water shortages are supplemented by irrigation. The crop water requirement is defined as the total water needed for evapotranspiration, from planting to harvest for a given crop in a specific climate region, when adequate soil water is maintained by rainfall and/or irrigation so that it does not limit plant growth and crop yield. Crop water requirements have been calculated per crop and per country using the methodology developed by FAO (Allen et al., 1998). In our calculations of virtual water contents we have excluded evaporation losses from storage reservoirs and irrigation canals.

If a primary crop is processed into a crop product (e.g. wheat processed into wheat flour), there is often a loss in weight, because only part of the primary product is used. In such a case we calculate the virtual water content of the processed product by dividing the virtual water content of the primary product by the so-called product fraction. The product fraction denotes the weight of crop product in ton obtained per ton of primary crop. If a primary crop is processed into two different products or more (e.g. soybean processed into soybean flour and soybean oil), we need to distribute the virtual water content of the primary crop to its products. We do this proportionally to the value of the crop products. If during processing there is some water use involved, the process water requirement is added to the virtual water content of the root product (the primary crop) before the total is distributed over the various root products. In summary, the virtual water content of a crop product is calculated as:

$$V[p] = (V[r] + PWR[r]) \times \frac{vf[p]}{pf[p]} \quad (3)$$

in which $V[p]$ is the virtual water content of product p (m^3/ton), $V[r]$ the virtual water content of the root product r (m^3/ton), $PWR[r]$ the process water requirement when processing the root product into processed products (m^3/ton), $pf[p]$ the product fraction and $vf[p]$ the value fraction. The latter is the ratio of the market value of the product to the aggregated market value of all the products obtained from the primary crop:

$$vf[p] = \frac{v[p] \times pf[p]}{\sum_{p=1}^{n} (v[p] \times pf[p])} \quad (4)$$

in which $v[p]$ is the market value of product p (US$/ton). The denominator is totalled over the n products that originate from the primary crop. In a similar way we can calculate the virtual water content for products that result from a second or third processing step. The first step is always to obtain the virtual water content of the input (root) product and the water necessary to process it. The total of these two elements is then distributed over the various output products, based on their product fraction and value fraction.

The virtual water content of live animals has been calculated based on the virtual water content of their feed and the volumes of drinking and service water consumed during their lifetime. Eight major animal categories were included in the study: beef cattle, dairy cows, swine, sheep, goats, fowls/poultry (meat purpose), laying hens and horses. The calculation of the virtual water content of livestock products has again been based on product fractions and value fractions, following the above described methodology.

Following Chapagain et al. (2006a), the national water saving ΔS_n (m^3/year) of a country n_i as a result of trade in product p has been defined as:

$$\Delta S_n[n_i, p] = V[n_i, p] \times I[n_i, p] - V[n_i, p] \times E[n_i, p] \quad (5)$$

where V is the virtual water content (m^3/ton) of the product p in country n_i, I the amount of product p imported (ton/year) and E is the amount of product exported (ton/year). Obviously,

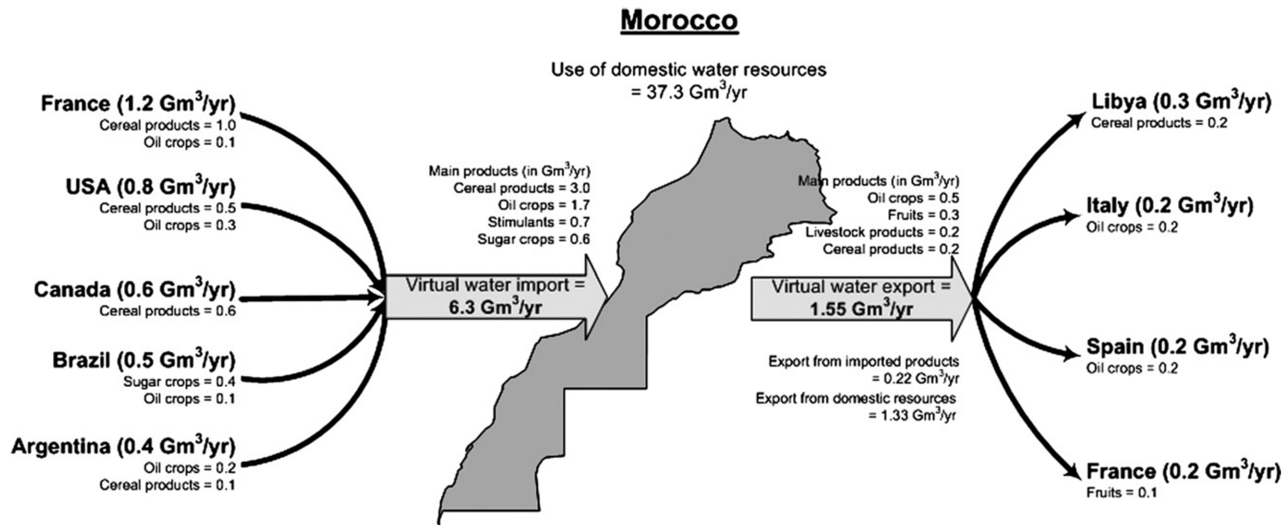

Fig. 1 – Virtual water balance of Morocco (insofar related to trade in agricultural commodities).

ΔS_n can have a negative sign, which means a net water loss instead of a saving.

The global water saving ΔS_g (m^3/year) through the trade in a product p from an exporting country n_e to an importing country n_i, is:

$$\Delta S_g[n_e, n_i, p] = T[n_e, n_i, p] \times (V[n_i, p]) - V[n_e, p] \quad (6)$$

where T is the amount of trade (ton/year) between the two countries. The global saving is thus obtained as the difference between the water productivities of the trading partners.

3. Virtual water flows and balances

The calculations show that both Morocco and the Netherlands import more virtual water than they export, which makes them dependent on water resources elsewhere in the world (Figs. 1 and 2).

In the period 1997–2001 Morocco imported 6.3 billion m^3/year of water in virtual form (in the form of agricultural commodities), while it exported 1.6 billion m^3/year. In Morocco itself, water use in the agricultural sector was 37.3 billion m^3/year. The import of cereals was responsible for 3.0 billion m^3/year of virtual water import. The most important sources of cereals were France, Canada and the USA. Import of oil crops was the second most import source of virtual water import into Morocco (1.7 billion m^3/year). Most oil crops were imported from the USA, Argentina, the Ukraine, France, Brazil and the Netherlands. Other agricultural commodities responsible for significant virtual water import to Morocco were stimulants such as coffee and tea (0.7 billion m^3/year) and sugar (0.6 billion m^3/year).

The export of virtual water from Morocco particularly relates to the export of oil crops (0.54 billion m^3/year), fruits (0.32), cereals (0.25) and livestock products (0.23). Italy and Spain are the most important destinations of the oil crops;

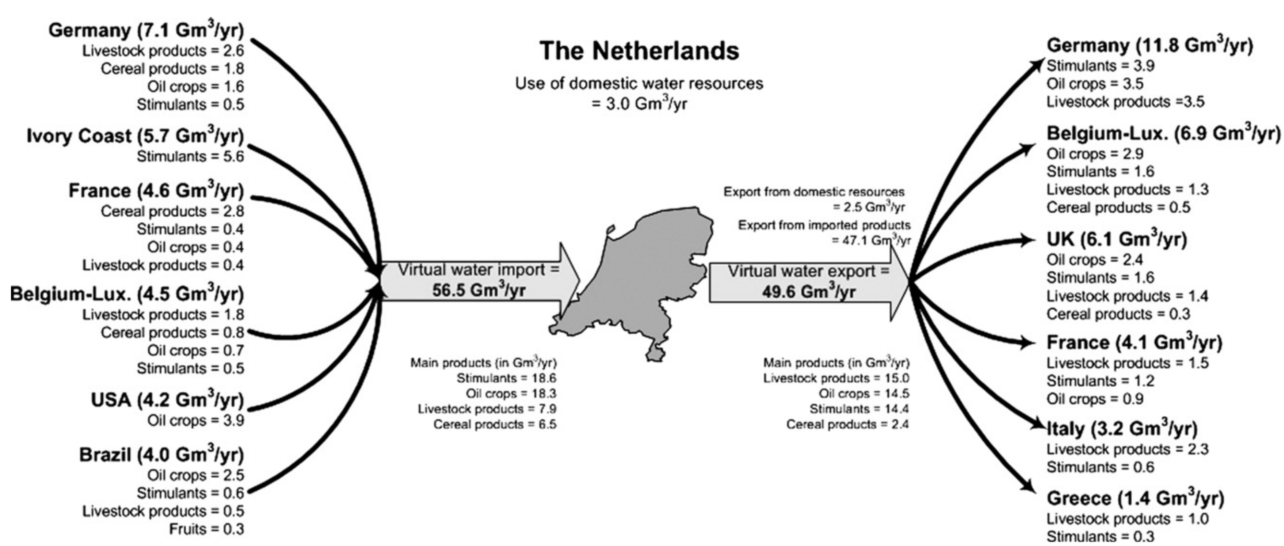

Fig. 2 – Virtual water balance of the Netherlands (insofar related to trade in agricultural commodities).

France and the Russian Federation are the largest customers of fruits; and Libya takes most of the cereals. About 4% of the water used in the Moroccan agricultural sector is applied for producing export products. The remainder of the water is applied for producing products that are consumed by the Moroccan population. From a water resources point of view, it seems appropriate that most of the scarcely available water in Morocco is being used for producing commodities for domestic consumption and not for export. From an economic point of view it would be worth checking whether the exported commodities yield a relatively high income of foreign currency per unit of water used (not done in this study).

In the period 1997–2001 the Netherlands imported 56.5 billion m^3/year of water in virtual form (in the form of agricultural commodities) and exported 49.6 billion m^3/year. Water use in the agricultural sector in the Netherlands itself was 3.0 billion m^3/year. The imports of stimulants and oil crops were responsible for respectively 18.6 and 18.3 billion m^3/year of virtual water import. The most important sources of stimulants (cocoa, coffee, tea) were Ivory Coast, Ghana, Cameroon, Nigeria, Brazil, Colombia, Kenya, Uganda and Indonesia. Oil crops came from countries such as the USA, Brazil and Argentina. Import of livestock products and cereal products were the third and fourth most import source of virtual water import into the Netherlands (7.9 and 6.5 billion m^3/year respectively). Most livestock products were imported from the neighbouring countries Germany and Belgium. Most cereals came from France and Germany. Other agricultural commodities responsible for significant virtual water import to the Netherlands were fruits (1.8 billion m^3/year) and sugar (1.0 billion m^3/year).

Unlike Morocco, the Netherlands has an important through-trade, which means that much of the imports are exported again in the same or a processed form. As a result, most (about 95%) of the virtual water exported from the Netherlands is not Dutch water, since it can be traced back to countries where the Netherlands imported from. The virtual water export from the Netherlands related to export of stimulants (not grown in the Netherlands) can for instance be traced back to countries such as Ivory Coast (cocoa) and Brazil (coffee).

4. Agricultural water footprints of Morocco and the Netherlands

Morocco, with a population of 28 million people, has an agricultural water footprint of 42.1 billion m^3/year, while the Netherlands, with 16 million inhabitants, has an agricultural water footprint of 9.9 billion m^3/year. Both countries have a significant external water footprint (Figs. 3 and 4). The external water footprint of Morocco is 6.1 billion m^3/year. The water dependency of Morocco – its dependence on foreign water resources, defined as the ratio of the external to the total water footprint – is 14%. The water self-sufficiency – defined as the ratio of the internal to the total water footprint – is thus 86%. In sequence, Morocco mostly depends on virtual water import from France, the USA, Canada, Brazil and Argentina.

The total agricultural water footprint of the Netherlands breaks down in an internal footprint of 0.5 billion m^3/year and an external footprint of 9.4 billion m^3/year. The Dutch water self-sufficiency in fulfilling the water needs for the consumption of agricultural commodities is thus 5% and the water dependency 95%. In other words: the total volume of water used outside the Netherlands for producing agricultural products consumed by the Dutch is twenty times the volume of water used in the Netherlands itself. These numbers show the relevance of the water footprint concept as an alternative indicator of water demand. The agricultural water demand by the Dutch community from a production perspective is 3.0 billion m^3/year (the actual use of water in the agricultural sector in the Netherlands), while the water demand from a consumption perspective is 9.9 billion m^3/year (the global water footprint).

Morocco has an average agricultural water footprint of 1477 m^3/cap/year, while the Netherlands has a footprint of 617 m^3/cap/year. The four major factors determining the per capita water footprint of a country are: volume of consumption (related to the gross national income); consumption pattern (e.g. high versus low meat consumption); climate (growth conditions); and agricultural practice (water use efficiency). The latter two factors are unfavourable for the Moroccan water footprint.

5. Water savings

Trade between the Netherlands and Morocco generates virtual water flows from the Netherlands to Morocco and vice versa (Fig. 5). The net flow however goes from the Netherlands to Morocco. Morocco uses a small portion of its domestic water resources (50 million m^3/year) for producing fruits, oil crops, nuts, stimulants and sugar for export to the Netherlands. The flow of virtual water from the Netherlands to Morocco is 140 million m^3/year and is largely related to the trade in cereal products, oil crops and livestock products. It is worth mentioning here that a part of the virtual water flow from the Netherlands to Morocco does not refer to water use in the Netherlands, because some of the products traded from the Netherlands to Morocco originate from elsewhere. In those cases, the Netherlands was only an intermediate station. For example, the virtual water flow related to the trade in soybean oil crude (53 million m^3/year) from the Netherlands to Morocco, can be traced back to countries such as Brazil and the USA.

If Morocco had to domestically produce the products that are now imported from the Netherlands, it would require 780 million m^3/year of its domestic water resources. Morocco thus saves this volume of water as a result of trade with the Netherlands. The fact that the products imported from the Netherlands were produced with only 140 million m^3/year while it would have required 780 million m^3/year when produced in Morocco, means that – from a global perspective – a total water volume of 640 million m^3/year was saved.

The reason for the large differences of water use per unit of product in Morocco compared to the water use per unit of imported product is twofold. One reason is that in the Moroccan climate evaporative demand is relatively high, so that, other circumstances being equal, crops will consume more water than in for example more moderate climates. The second reason is that current agricultural yields in Morocco are very low (FAO,

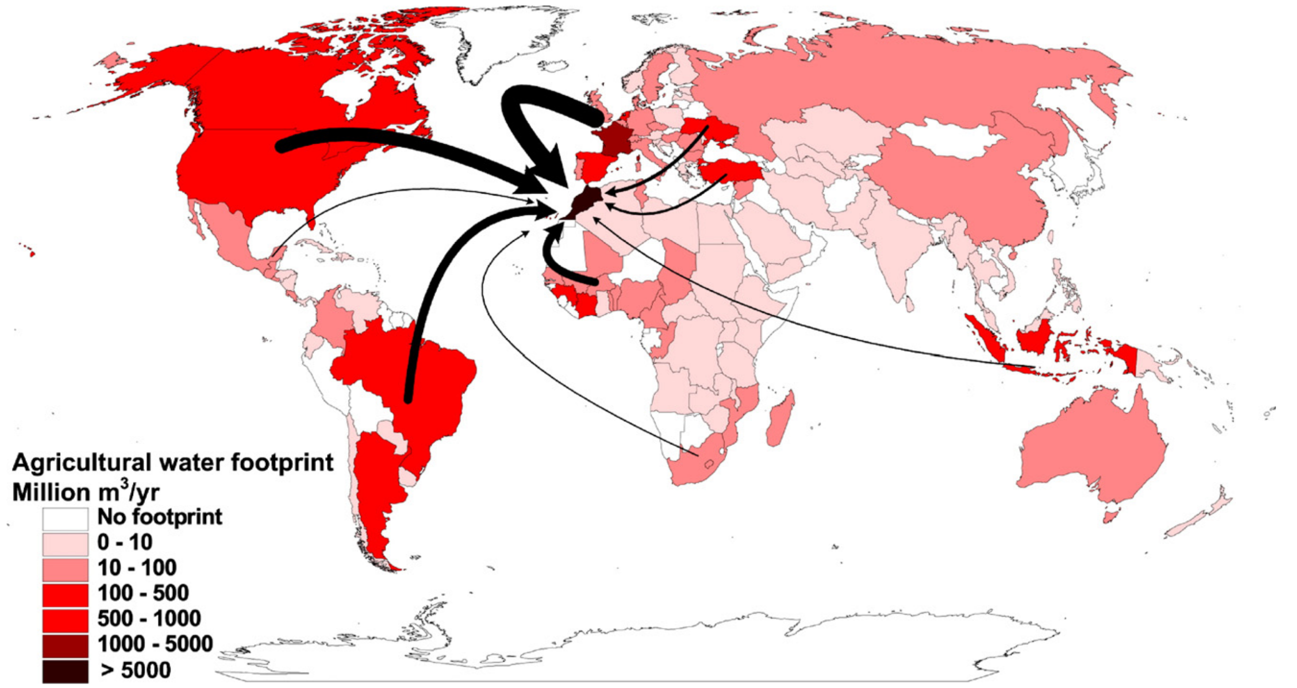

Fig. 3 – The global water footprint of the people in Morocco (insofar related to the consumption of agricultural commodities).

2005). Both factors together lead to a situation where maize produced in Morocco has a virtual water content of 12600 m^3/ton, while maize produced in the Netherlands has a virtual water content of 410 m^3/ton.

If we look at the total virtual water import of Morocco (6.3 billion m^3/year, see Fig. 1) the domestic water saving is much larger than the domestic water saving related to virtual water import from the Netherlands alone. According to our calculations, domestically producing the agricultural products that are currently imported to Morocco (period 1997–2001) would require 28.6 billion m^3/year. Thus, this is the total water volume saved in Morocco as a result of

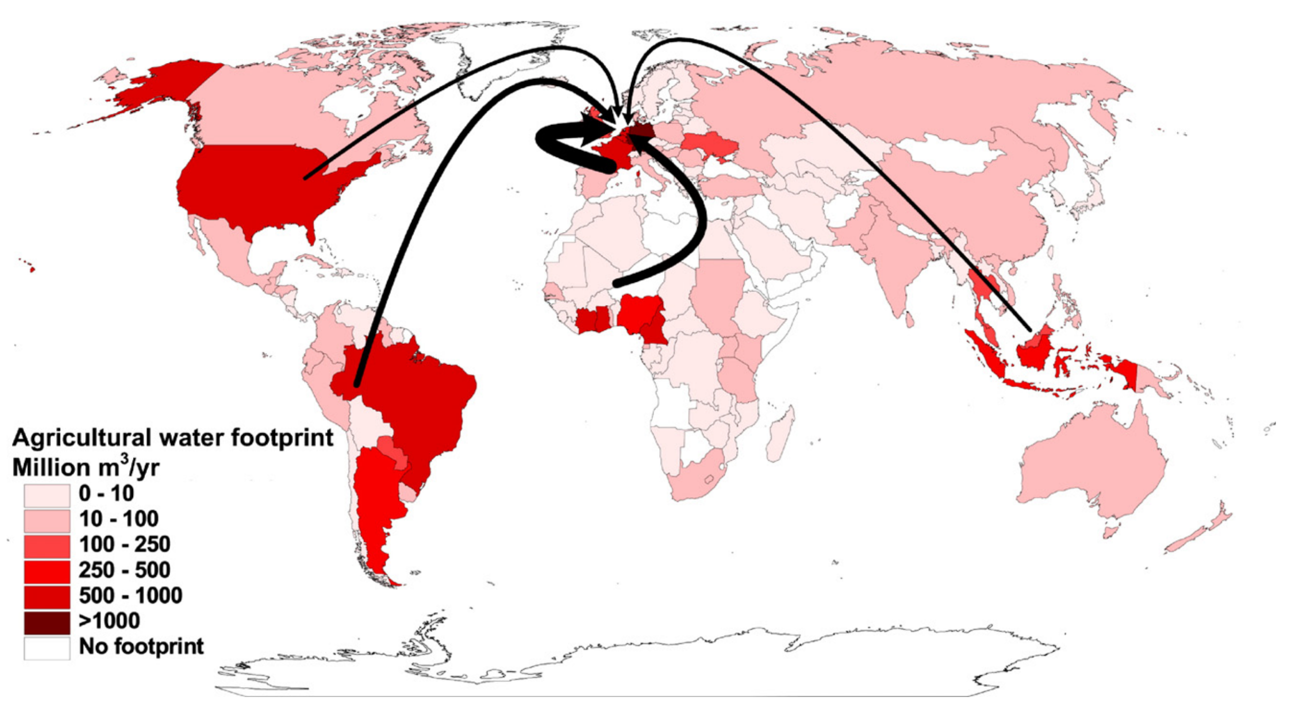

Fig. 4 – The global water footprint of the people in the Netherlands (insofar related to the consumption of agricultural commodities).

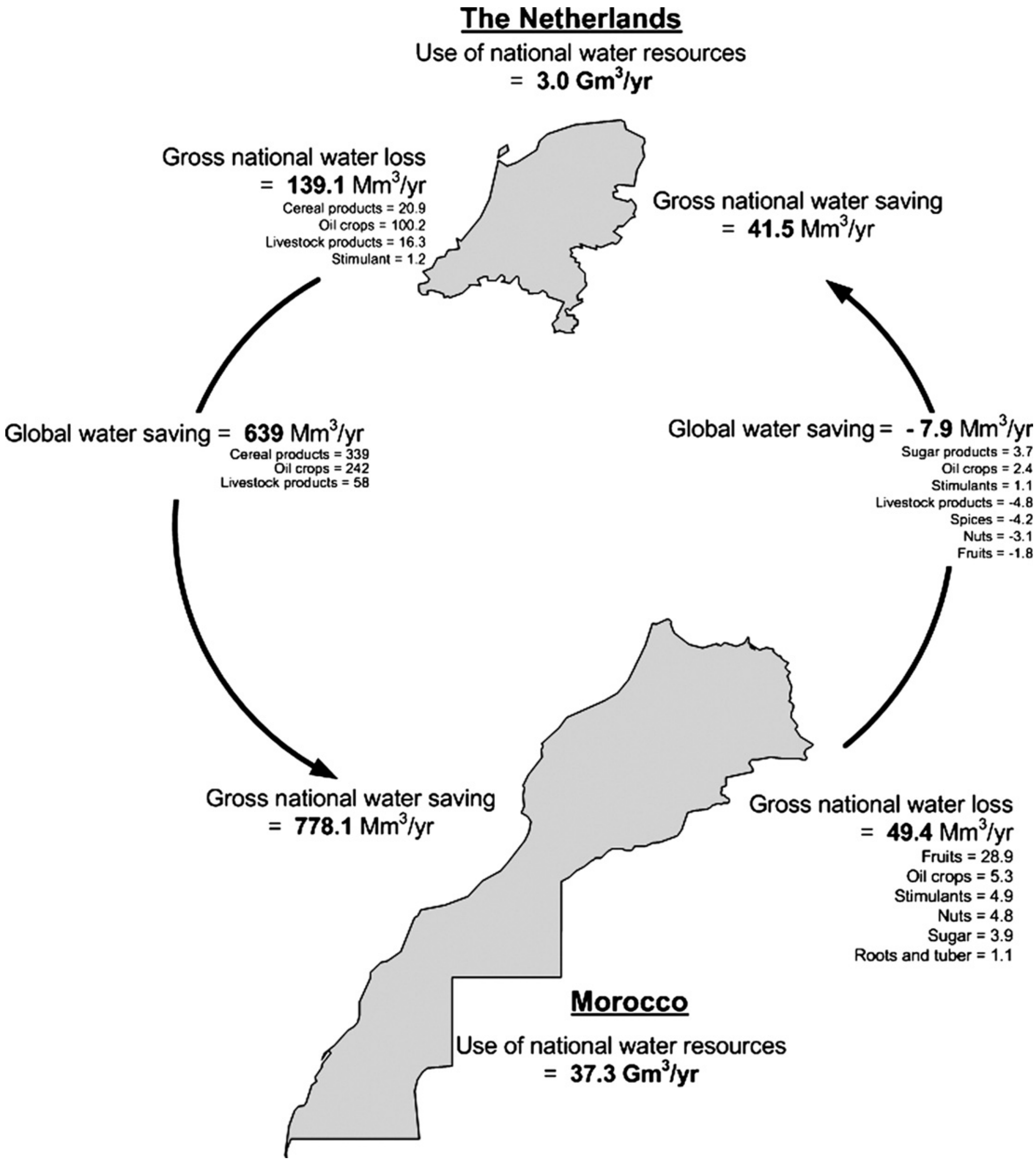

Fig. 5 – National water savings and losses and global water savings and losses as a result of trade in agricultural products between the Netherlands and Morocco.

agricultural imports. The global water saving is (28.6 – 6.3 =) 22.3 billion m^3/year.

6. Discussion

In this paper we show that Morocco and the Netherlands import water in virtual form, more than they export, so that in effect they both partially depend on water resources elsewhere. We also show that the agricultural trade between the Netherlands and Morocco is accompanied by a global water saving. We would like to emphasize that we present these results as an analytical fact without the intention to suggest that the virtual water flows revealed are *good* (e.g. because economically efficient or because saving water resources) or *bad* (e.g. because creating dependence or because externalising negative effects of water use without paying). The scope of this paper is not broad enough for those kinds of conclusion. Besides, we do not want to suggest that Morocco and the Netherlands import water in virtual form *because* they intend to save domestic water resources. Indeed, by importing virtual water they save domestic water resources, but this does not imply that the latter was an incentive for the first. International trade in agricultural commodities depends on a lot more factors than water, such as availability of land, labour, knowledge and capital, competitiveness in certain types of production, domestic subsidies, export subsidies and import taxes. As a consequence, international virtual water trade can most times not be explained on the basis of relative water abundances or shortages (Yang et al., 2003). So we fall short in explaining why the two countries have net virtual water import and in collecting grounds for judging the current trade in terms of positive and negative implications. What the paper however does show is that international agricultural trade can significantly influence domestic water demand and thus domestic water scarcity and that formulating international agricultural trade policy should therefore include an analysis of the implications in the water sector. The message is: international trade in agricultural products significantly influences the water appropriation in a country, a relation that has so far received little attention from both economists and water managers.

With increasing globalization of trade, global water interdependencies and overseas externalities are likely to increase. As visualised with the external water footprints of Morocco and the Netherlands, the consumption of imported products is connected to water use and related impacts in the countries where the products are grown and processed. For a semi-arid/arid country like Morocco, two essential political questions are: to what extent does it care about food self-sufficiency (producing its own food based on domestic water resources) and to what extent does it care about the use of domestic water resources to produce export products. Due to the limited availability of water, striving for food self-sufficiency will soon conflict with using water for producing export products. If food self-sufficiency is not an issue, from a water-resources point of view it would make sense to stimulate export of products with a relatively high foreign currency income per unit of water used (e.g. citrus fruit, olives) and to import products that would otherwise require a relatively large amount of domestic water per unit of dollar produced (e.g. cereals).

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