Papeles de Agua Virtual

Are virtual water «flows» in Spanish grain trade consistent with relative water scarcity?

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Número 1

Fundación Marcelino Botín

Los *Papeles de Agua Virtual* conforman una serie de documentos de trabajo creados al amparo del proyecto de investigación *Análisis de la Huella Hidrológica y del Comercio de Agua Virtual en España*, financiado por la Fundación Marcelino Botín dentro del convenio entre la Universidad Politécnica de Madrid y esta fundación, en el que participa también como codirector científico externo el Profesor y Académico Ramón Llamas Madurga.

La creciente utilización de los conceptos de agua virtual y de huella hidrológica ha propiciado la realización de un estudio en profundidad aplicado a España. Con la finalidad de evaluar la aplicación de ambos conceptos a la gestión de los recursos hídricos y someterlos a debate, los *Papeles de Agua Virtual* (PAV) recogen parte de los resultados obtenidos durante la investigación. Esta nueva colección de documentos, que sucede a la de *Papeles de Aguas Subterráneas* (PAS) también auspiciada por la Fundación Marcelino Botín entre 1999 y 2004, recoge los desarrollos metodológicos y los resultados obtenidos del estudio sobre el comercio de agua virtual y la huella hidrológica. Los PAV siguen así la estela de los PAS, que tanta influencia y repercusión tuvieron en España. Además de contribuir al debate científico sobre la política del agua, los PAV tienen como objetivo más importante orientar los resultados del estudio hacia aspectos prácticos que sean de aplicación para hacer más eficiente el uso de los recursos hídricos, teniendo en cuenta los procesos de cambio global y las relaciones comerciales de España con la UE y el resto del mundo. En esta serie se incluye también un PAV sobre la huella hidrológica de la cuenca del Guadiana que corresponde a un estudio realizado conjuntamente entre este proyecto y el caso de estudio de la cuenca del Guadiana que dirige el profesor M. Ramón Llamas dentro del proyecto de la Unión Europea llamado NeWater.

Los PAV se pueden descargar gratuitamente de las páginas web del Centro de Estudios e Investigación para la Gestión de Riesgos Agrarios y Medioambientales, centro de I+D de la Universidad Politécnica de Madrid (www.ceigram.upm.es), y también desde la web de la Fundación Marcelino Botín (www.fundacionmbotin.org).

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ARE VIRTUAL WATER «FLOWS» IN SPANISH GRAIN TRADE CONSISTENT WITH RELATIVE WATER SCARCITY?

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Table of contents

ARE VIRTUAL WATER «FLOWS» IN SPANISH GRAIN TRADE CONSISTENT WITH RELATIVE WATER SCARCITY?

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Abstract

Virtual water adds a new dimension to international trade, and brings along a new perspective about water scarcity and water resource management. Most virtual water literature has focused on quantifying virtual water «flows» and on its application to ensure water and food security. Nevertheless, the analysis of the potential gains from international trade, at least from a water resources perspective, needs to take into account both spatial and temporal variations of blue (groundwater and stream flow) and green (soil moisture) water, as well as the socioeconomic and policy conditions. This paper evaluates whether grain trade in Spain is consistent with relative water scarcity. For this purpose, the study estimates the volume and economic value of virtual water «flow» through international grain trade for the period

1997-2005, which includes three years with different rainfall levels. The calculations show that Spain is a net virtual water «importer» through international grain trade. The volume of net virtual water «imports» amounts to 3420, 4383 and 8415 million m^3 in a wet (1997), medium (1999) and dry (2005) years, respectively. Valuing blue water at its shadow price or scarcity value, blue water «exports» oscillate between 0.7 and 34.2 million Euros for a wet and dry year, respectively. Overall, grain trade is apparently consistent with relative water scarcity as net imports increase in dry years. However, the evolution of grain exports, expressed as a variation in quantity and volume, does not match the variations in resource scarcity. A disaggregated crop analysis reveals that there are other factors, such as quality, product specialization or the demand for a standardized product, which also influence trade decisions and are not included in the notion of virtual water. These facts, among others, can therefore create potential distortions in the application of virtual water to the analysis of specific trade patterns. Nevertheless, from a water resources perspective, virtual water can bring important insights across countries for improving water and land management globally, fostering adaptation strategies to climate change and to transboundary resource management.

Keywords: Virtual water; International trade; Green and blue water; Water scarcity; Water use efficiency

1. Introduction

Expressed in physical units, virtual water is the volume of water that is used to produce a commodity (Allan, 1998). When this commodity is exchanged through international trade virtual water «flow» takes place. The term virtual water adds a new dimension to international trade, and brings along a new perspective about water scarcity and water resources management. In this sense, virtual water is linked to water productivity, geographical location and to the site-specific socioeconomic setting. It is commonly referred as a strategy to increase global water use efficiency, while providing a global solution to local water scarcity problems (Yang and Zehnder, 2002; Fraiture *et al.*, 2004; Hoekstra and Hung, 2005).

When thinking about the economic value of water it is essential to consider green and blue water separately. Green water is the infiltrated rainwater stored in unsaturated soils (Falkenmark, 2003). It is the water source for rainfed agriculture. Blue water refers to groundwater and stream flow (ibid.). Irrigated agriculture is the major blue water consumer. Up to 80% of blue water resources are used for irrigation purposes in the world. From an economic perspective, as stated at the Dublin Conference in 1992, blue water should be considered an economic good. However, there is disagreement about whether green water has an economic value. So far, it has been technically and conceptually complex to define the opportunity cost and to attach a market price to green water. Recent studies show that it might be possible to define the economic value of green water through institutional arrangements such as payments for proper land and green and blue water management at river basin scale (Hoff, 2006).

Most of virtual water literature has mainly focused on quantifying the volume of virtual water «flow» and on its application to ensure water and food security. However, there is a general lack of policy-oriented approaches to assess the trade-offs of implementing a virtual water strategy (Yang and Zehnder, 2007). The analysis of the potential gains from international trade, from a water resources perspective, needs to take into consideration both spatial and temporal variations of blue and green water and the socioeconomic and policy conditions. Overall, the effectiveness of virtual water must be examined against the opportunity cost of green and blue water as well as crop water productivity gaps among trading partners.

International trade indirectly brings about a «virtual» re-distribution of global water resources. By shifting the production to those areas with higher water productivity and lower opportunity cost, scarce water resources might be allocated to those activities which generate greater economic value (Wichelns, 2004). From an economic point of view, this virtual water strategy seems reasonable, although several studies suggest that food imports do not always match with relative water scarcity (e.g. Yang *et al.*, 2003; Brichieri-Colombi, 2004; Fraiture *et al.,* 2004; Ramírez-Vallejo and Rogers, 2004; Kumar and Singh, 2005). Trade decisions obey mainly to the relative prices and productivity of the production resources, water being one of the scarcest in agriculture. Therefore, the role of international trade to mitigate, or increase, the effects of water scarcity requires a comprehensive analysis of trade patterns, taking into account both resource endowments and economic scarcity.

The main objective of this study is to evaluate whether grain trade in Spain is consistent with relative water scarcity. For this purpose, this study estimates the volume and economic value of virtual water «flow» through international grain trade in Spain. The main contributions

of this study are (i) the distinction and separate estimation of green water and blue water in rainfed and irrigated agricultural production. This is essential for arid and semiarid countries such as Spain. (ii) The economic valuation of blue virtual water «exports». The paper's new approach to virtual water «flow» includes assigning an economic value to blue virtual water «exports». (iii) The time and spatial dimension, as the study covers the period 1997-2005 which includes three years with different rainfall levels and estimates monthly crop water requirements for all the Spanish Autonomous Communities.

2. Agricultural trade and water resources

International trade data shows that Spain is a net importer of agricultural products, measured in quantity terms, but a net exporter, measured in economic value (INE, 2007). This is mainly due to the relative amount and economic value of crops traded. Whereas grain has a low economic value, as compared to fruit and vegetables, the imported tonnage of grain is nearly the same as the one exported through fruits and horticultural products (Table 1). This fact explains that Spain can be considered as either a net importer or a net exporter of agricultural products depending on the terms of analysis.

In Spain, agriculture productivity is strongly linked to blue water access. This is shown by the gross margin difference between irrigated and rainfed agriculture. Furthermore, in the case of irrigated agriculture, water productivity is highly variable among crops. For example, in order to generate 1000 € of added value grain products require approximately 7000 m^3 of irrigation water while horticultural products require 700 m^3 (MMA, 2007a).

TABLE 1. *International crop trade in Spain. Years 1994 and 2004*

	IMPORTS				EXPORTS			
	Quantity (*1000 t)		Value (*1000 €)		Quantity (*1000 t)		Value (*1000 €)	
	1994	2004	1994	2004	1994	2004	1994	2004
Total crop trade	11,708	17,775	3,023,579	5,259,907	9,803	12,384	4,775,520	8,742,178
Vegetables	2,754	3,114	513,897	835,916	2,469	4,203	1,498,425	3,354,569
Fruits	579	1,171	428,585	1,233,512	4,293	5,523	2,537,662	4,267,857
Cereals	5,267	9,298	832,934	1,352,931	1,956	1,245	238,464	307,779

Source: Modified from INE (2007).

In Spain cereals account for 40% of crop land, 86% of which is rainfed (MAPA, 2006). Therefore, the relative high weight that green water has for grain production is not surprising. Soil provides a natural storage of (green) water directly available for crop production. Although green water plays a key role in world food supply, it has been frequently neglected on studies about water and trade relations, partly due to the complexity which entails its estimation (Yang and Zehnder, 2007). Moisture storage capacity and consequently green water availability rely heavily on land and crop management, as well as on climate and soil characteristics. Kumar and Singh (2005) suggest that as a consequence of neglecting green water resources a relationship was not found between virtual water «imports» and water resources availability.

The fact that Spain exports high valued crops and imports less valuable crops shows the relevance of considering both volume and economic value of the virtual water «exchanged». However, from an economic point of view it is important to take into account the type of water consumed (green and/or blue), as well as the productivity of other relevant factors, such as land or labour. Furthermore, to obtain proper estimations of the potential gains from international trade,

and consequently from virtual water «flows», the actual value of water resources should be reflected in trade patterns (Wichelns, 2003). Otherwise, international trade would act as a mechanism to shift environmental pressures to distant locations.

Currently, virtual water «flows» are mainly subordinated to world trade policies. According to Llamas (2005), water policies have no influence on World Trade Organization (WTO) rules. However, WTO policies affect agricultural policies, and these in turn affect irrigation water use. The evolution of water consumption in arid and semiarid countries has been strongly determined by water and agricultural policies (Varela-Ortega, 2007a).

3. METHOD

Our methodology is based on the one proposed by Hoekstra and Hung (2002) and Hoekstra and Chapagain (2008). It includes a number of modifications to evaluate separately green and blue virtual water content in rainfed and irrigated production for all Spanish Autonomous Communities during 1996-2005. The rationale for separating these two tracts of water resources used for grain production is based on the extreme sensitivity of the relative proportion of both types of water to drought and climate variability, as well as on its economic implications.

3.1. Calculation of virtual water content

Virtual water content refers to the unitary volume of water required to produce a commodity. The virtual water content of primary crops is based on the estimation of crop water requirements (*CWR*, m^3/ha) and effective rainfall (P_{eff}, mm).

Crop water requirements are assumed to be equal to crop evapotranspiration (ET_c, mm/month) under standard conditions, this means that water does not limit plant growth and crop yield. ET represents crop evaporative demand and is calculated by multiplying the reference evapotranspiration (ET_o, mm/month) by the crop coefficient K_c over the growing period. Crop water requirements are calculated following the methodology developed by the Food and Agriculture Organization (Allen *et al.*, 1998).

Effective rainfall is defined as the amount of rainfall water which is actually available for plant intake (Dastane, 1978; Brouwer and Heibloem, 1986). Therefore, the irrigation requirement is zero if effective rainfall is greater than crop water requirements.

Green and blue water evapotranspiration is defined as the evaporative demand satisfied by green and blue water, respectively. Green water evapotranspiration (ET_g, mm/month) is calculated as the minimum value between effective rainfall and crop water requirements. For irrigated crops, blue water evapotranspiration (ET_b, mm/month) is equal to the difference between crop water requirements and green water evapotranspiration.

$$ET_g\left[c,q,m\right] = \min\left(CWR\left[c,q,m\right], P_{eff}\left[q,m\right]\right) \quad (1)$$

$$ET_b\left[c,q,m\right] = \max\left(0, CWR\left[c,q,m\right] - ET_g\left[c,q,m\right]\right) \quad (2)$$

This calculation is carried out for crop c, Autonomous Community q and month m. Crop water consumptive use (CWU, m^3/ha) over the complete growing period t is calculated either by accumulation of monthly green and blue water evapotranspiration or by referring the variables included in equations (1) and (2) to the complete growing

period. In the former case, green and blue water balances (Eq. 1 and 2) are calculated on a monthly basis and total crop water consumptive use is the sum of monthly values over the growing period. Consequently, green water that is not used by crops along a specific month is lost to deep drainage and runoff. When variables are referred to the entire growing period green water that is not consumed in one particular month might be stored in the soil profile to meet later crop water requirements. Under the assumption of green water storage CWU_g and CWU_b values might be substantially different to those calculated without taking into consideration green water accumulation. Therefore, green and blue crop water use is defined by the following intervals:

$$CWU_g\left[c,q,t\right] = \left(10 \times \sum_{m=1}^{lgp} ET_g\left[c,q,m\right], 10 \times \min\left(\sum_{m=1}^{lgp} CWR\left[c,q,m\right], \sum_{m=1}^{lgp} Peff\left[q,m\right]\right)\right) \quad (3)$$

$$CWU_b\left[c,q,t\right] = \left(10 \times \sum_{m=1}^{lgp} ET_b\left[c,q,m\right], 10 \times \max\left(0, \sum_{m=1}^{lgp} CWR\left[c,q,m\right] - \sum_{m=1}^{lgp} ET_g\left[c,q,m\right]\right)\right) \quad (4)$$

Where, *lgp* stands for the length of the growing period measured in months and the factor 10 is to convert mm into m^3/ha.

Green virtual water content (V_g, m^3/ton) is calculated as the ratio between green crop water use and crop yield (Y, ton/ha). In parallel, blue virtual water content of a primary crop (V_b, m^3/ton) is calculated as the blue component in crop water use divided by the crop yield. Since rainfed and irrigated crop yields are usually different their respective virtual water content is estimated separately, calculating one green component for rainfed crops an other green and blue virtual water content for irrigated crops. Therefore, green and blue virtual water content is estimated by crop c, Autonomous Community q and growing period in year t.

$$V_g\left[c,q,t\right]=\frac{CWU_g\left[c,q,t\right]}{Y\left[c,q,t\right]} \tag{5}$$

$$V_b\left[c,q,t\right]=\frac{CWU_b\left[c,q,t\right]}{Y\left[c,q,t\right]} \tag{6}$$

CWU_g and CWU_b values refer to those calculated taking into account, the possibility of storing and non storing green water for the following cropping period. Thus, if there is a difference between both figures, two different results for green and blue virtual water content are obtained.

For assessing crop virtual water «exports» green and blue virtual water contents are aggregated at national level in a number of steps. First, the national average of green and blue virtual water content in rainfed and irrigated agriculture is calculated as the weighted sum of the correspondent values in the different Autonomous Communities. Second, an overall national average value of green and blue virtual water content is estimated by weighting green and blue virtual water content in both rainfed and irrigated agriculture by its relative national production. This last value accounts for the weighted average volume of green and blue virtual water that is required to produce one kilogram of crop c in Spain.

3.2. Calculation of volumetric virtual water «flow»

Virtual water «flow» is calculated by multiplying trade flows by their associated virtual water content, estimated at the production site. Virtual water «export» (VW_E, m^3/yr)

concerns the export of products produced in Spain. Virtual water «import» (VW_I, m^3/yr) refers to the import of products produced outside Spain. Virtual water content values of imported products have been taken from Chapagain and Hoekstra (2004). In this case, it is not possible to distinguish whether virtual water «imports» are blue and/or green.

$$VW_{Eg}\left[c,t,n_e\right]=T\left[c,t,n_e\right]\times V_g\left[c,t,n_e\right] \tag{7}$$

$$VW_{Eb}\left[c,t,n_e\right]=T\left[c,t,n_e\right]\times V_b\left[c,t,n_e\right] \tag{8}$$

in which VW_{Eg} and VW_{Eb} denote green and blue virtual water «exports» (m^3/yr) from exporting country n_e in year and through crop c. T represents the quantity exported (ton/yr) of crop c, in year t and from country n_e. V_g and V_b represent green and blue virtual water content (m^3/ton) in crop c produced in the exporting country in year t. Values with and without green water accumulation, referred in the previous section, are taken into account. Virtual water «exports» (VW_E) is the sum of the green and blue components.

$$VW_I\left[c,t,n_i\right]=T\left[c,t,n_i\right]\times V_i\left[c,n_e\right] \tag{9}$$

VW_I denotes Spanish virtual water «imports» (m^3/yr) from importing country n_i in year t and due to imports in crop c. T refers to the quantity imported (ton/yr) through crop c by importing country n_i in year t. V_I represents the virtual water content of imported crop c from exporting country n_e . This value remains constant for the period under consideration (1997-2005), since Chapagain and Hoekstra (ibid.) estimated a unique value based on year 1999.

Net virtual water «imports» ($NVWI_I$, m^3/yr) are calculated as virtual water «imports» minus virtual water «exports». The balance is established for crop c in year t.

$$NVW_I\left[c,t\right] = VW_I\left[c,t\right] - VW_E\left[c,t\right] \tag{10}$$

Net virtual water «imports» might be either positive or negative. Therefore, the country might be a net «importer» or a net «exporter», respectively.

3.3. Calculation of economic virtual water «flow»

From an economic perspective, only blue virtual water «exports» are valued, since it is dubious to assume a value to green water. Furthermore, the scarcity value of «imported» blue virtual water is unknown. Therefore, only, internal blue water is valued at its shadow price or scarcity value.

Shadow price refers to the irrigators' willingness to pay for an extra unit of water and it is equivalent to the marginal value of their available water endowments. Marginal value measures the benefits derived from an increase in water availability. In order to estimate the marginal value of water it is necessary to model how water generates value (Hanemann, 2006). Shadow price is also a useful tool to measure, in economic terms, the effects of resource depletion and degradation. In such a way, it could serve as a guide for water pricing policies (Dinar *et al.*, 1997). Therefore, using the shadow price of water to measure the economic value of blue water seems consistent with the analysis of virtual water trade in arid countries, where the distinction between green and blue water is essential to relate land and water management to drought and climate variability.

Economic value of blue virtual water «exports» is estimated in years 1997, 1999 and 2005, which are defined as a wet, medium and dry year, respectively. Water scarcity values have been selected based on a comprehensive literature review, which we address later. As a result, blue water values are defined for each year and river basin. Each Autonomous Community is identified with a specific river basin, although the administrative and basin boundaries do not perfectly overlap, and with a specific shadow price. The shadow price of blue water in Spain (P_s, €/m^3) is therefore calculated as the weighted average of the values of each Autonomous Community values in each year t. Autonomous Community values are weighted according to their relative irrigated production (P_{irr}, ton).

$$P_s\left[t\right] = \sum_q P_s\left[q,t\right] \times \frac{P_{irr}\left[q,t\right]}{\sum_q P_{irr}\left[q,t\right]} \tag{11}$$

The economic value of blue virtual water «exports» by crop c, year t and country n_e is equal to the product of volumetric blue virtual water «exports» and the shadow price:

$$EVW_{Eb}\left[c,t,n_e\right] = VW_{Eb}\left[c,t,n_e\right] \times P_s\left[t\right] \tag{12}$$

where, EVW_{Eb} denotes economic blue virtual water «exports» (€).

4. DATA SOURCES

4.1. Agricultural data

Data related to crop area, crop yield and crop production by Autonomous Community and production system (i.e. rainfed and irrigated) have been taken from the Agricultural and Food Statistics Yearbook, published by the Spanish Ministry of Agriculture (MAPA, 2007).

With regard to crop parameters, crop coefficients in different crop development stages (initial, middle and late stage) and crop calendars were adjusted based on Allen *et al.* (1998), the Spanish Ministry of Agriculture (MAPA, 2001) and Instituto Técnico Provincial from Albacete (ITAP, 2007). Although there are regional differences, crop parameters are assumed to be equal in all Autonomous Communities.

4.2. Climatic data

Average monthly rainfall and reference evapotranspiration data at Autonomous Community level have been obtained from the National Institute of Meteorology (INM, 2007). Climatic data are available for the nine-year period 1996-2005.

4.3. Trade data

Data related to trade have been obtained from the Agricultural and Food Statistics Yearbook of the Spanish Ministry of Agriculture (MAPA, 2007).

4.4. Economic data

The shadow prices of blue water, as reported in Table 2, have been taken from previous studies carried out by other research studies.

The shadow price of blue water is assumed to be equal to 0.005 €/m^3 in a wet year. This value has been chosen based

on the studies by Calatrava and Garrido (2005), Gómez-Limón and Martínez (2006) and Varela-Ortega (2007b). In an average year this value varies between 0.02 and 0.08 €/m^3, depending on the river basin bling taken under consideration. These values have been chosen based on the results obtained by Calatrava and Garrido (2005), Iglesias *et al.* (2003; 2007) and Gómez-Limón and Martínez (2006). In a dry year the shadow price is even higher and oscillates between 0.15 and 0.30 €/m^3.

TABLE 2. *Blue water shadow price by Autonomous Community and year (€/m^3)*

Autonomous Communities	*Wet year 1997*	*Medium year 1999*	*Dry year 2005*
Galicia, Asturias, Cantabria, País Vasco, La Rioja, Navarra, Aragón, Cataluña, Castilla León, Comunidad Madrid	0.005	0.02	0.15
Castilla Mancha, Extremadura, Comunidad Valenciana, Región Murcia, Andalucía	0.005	0.08	0.30

Source: Own elaboration based on Albiac (2006), Arrojo (2001), Calatrava and Garrido (2005), Iglesias et al. (2003;2007), Gómez-Limón and Martínez (2006) and Varela-Ortega (2007a; 2007b).

Although roughly selected, blue water shadow prices used in the present study attempt to provide, from an economic perspective, a first estimation of blue virtual water «exports». Data improvements would lead to more accurate estimates of actual gains derived from international trade and virtual water «flows».

4.5. Virtual water content of crop imports

This data have been taken from Chapagain and Hoekstra (2004).

5. GREEN AND BLUE VIRTUAL WATER CONTENT

The following section is a summary of the main results obtained at national level in three years with different rainfall level. For the calculated values it is assumed that crop water requirements refer to crop evapotranspiration under optimal growth conditions and without taking into account drainage and runoff loses.

As mentioned earlier, virtual water content is bounded by the values obtained when taking and not taking into account green water storage. The upper bound of green virtual water content is determined under the assumption of green water storage all over the growing period; whereas the lower bound is defined by restricting green water to the specific monthly rainfall. On the opposite, the upper bound of blue virtual water content is determined when green water storage is not possible and the lower bound when this previous restriction is relaxed. Therefore, if green water does not totally meet crop water requirements a supplement of blue water is required. Thus, greater green water availability is associated with lesser blue water complement. In irrigated agriculture, although the ratio between green water and blue water is dependent on the assumption of green water accumulation, the final virtual water content is the same. This follows from the assumption that the crop water requirements are fully met.

Two key aspects concerning green and blue virtual water content should be highlighted in reference to the results reported in Table 3. First, the virtual water content fluctuates depending on the crop, type of year (wet, medium or dry) and production system (irrigated or rainfed). Second, there is a marked difference between the results reported in Table 3 and those calculated by Chapagain and Hoekstra (2004).

TABLE 3. *Ranges of green and blue virtual water content in Spanish grain production (m^3/ton)*

			Green virtual water content (m^3/ton)		Blue virtual water content (m^3/ton)	Virtual water content(m^3/ton)	Chapagain and Hoekstra (m^3/ton)
Crop	*Type year*	*Year*	*Rainfed*	*Irrigated*	*Irrigated*		
	Wet	1997	447 - 1235	231 - 649	163 - 582	507 - 1166	–
Wheat	Medium	1999	305 - 334	151 - 164	640 - 653	402 - 426	1227
	Dry	2005	252 - 295	95 - 106	862 - 872	403 - 437	–
	Wet	1997	416 - 907	84 - 104	528 - 537	624 - 641	–
Maize	Medium	1999	405 - 803	75 - 111	523 - 559	626 - 641	646
	Dry	2005	186 - 561	48 - 67	700 - 719	747 - 756	–
	Wet	1997	296 - 870	213 - 459	496 - 742	472 - 881	–
Barley	Medium	1999	260 - 275	139 - 145	807 - 813	361 - 374	1070
	Dry	2005	250 - 277	99 - 107	1389 - 1397	530 - 551	–
	Wet	1997		88	939	1027	–
Rice	Medium	1999	—*	54	925	978	1485
	Dry	2005		25	1151	1175	.

* Rice mainly cultivated under irrigated conditions.
Source: Chapagain and Hoekstra (2004) and own elaboration.

Green virtual water content is higher in a wet year because larger water volumes are available for plant intake. Furthermore, considering one specific crop, green virtual water content is higher in rainfed than in irrigated agriculture, since average yield is smaller on the other hand, Blue virtual water content is higher in dryer years. This is due to both higher crop water requirements and evaporative demands. In addition, cereal crop yields and effective rainfall are generally lower in dry years. Virtual water content in irrigated agriculture, which is equal to the sum of green and blue components, is usually higher than in rainfed agriculture, at least in dry and average years. Nevertheless, this result has to be analyzed considering our methodological assumptions. In the case of irrigated agriculture crop water requirements are assumed to be always fully satisfied.

Generally, the crop water requirement gap between rainfed and irrigated agriculture is not compensated by the relative difference in yields despite the fact that crop yield is usually higher in irrigated agriculture. Regarding variations among crops, these could be due to either different evaporative demands or differences derived from yields and rainfall levels.

We now comment on the differences between our results and those of Chapagain and Hoekstra (2004). Focusing on wheat and barley, these crops are mainly cultivated in rainfed agriculture; therefore, the ratio between green water availability and crop water requirements is usually lower than one. However, in the study of Chapagain and Hoekstra (ibid.), crop water requirements are always completely covered, irrespectively of the fact that crops might be grown under rainfed and irrigated regimes. Our approach differentiates the regimes and allows for rainfed crops to grow with moisture deficit. Furthermore, other factors explaining the differences are data sources and aggregation levels.

Virtual water content is somehow linked to crop water productivity. Building on this idea virtual water «flow» is also connected to water use efficiency and water «saving». By shifting the production to those areas with higher crop water productivity, countries can «save» water globally and, in the case of importing countries, also locally. In virtual water literature higher crop water productivity (ton/m^3) has been often related to lower virtual water content, which is logical from an economic and a resource based perspective. However, regarding crops such as wheat or barley, mainly cultivated under rainfed conditions, this conclusion might be misleading since higher virtual water contents are likely to be related to higher rainfall levels, considering non-linear production functions respective to water availability, and not to higher evaporative demands and lower yields, such as in the case of

crops mainly cultivated under irrigated conditions. Therefore, it is essential to be extremely careful when assessing both the differences in crop water productivity among countries and water «savings» from trade.

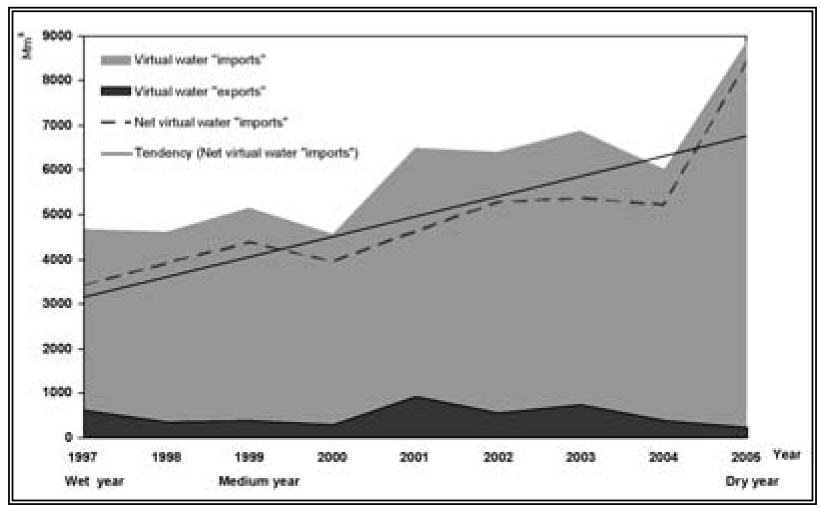
6. VIRTUAL WATER «FLOW»

6.1. Volumetric virtual water «flow»

Spain is a net virtual water «importer» through international grain trade. The volume of net virtual water «imports» equals 3420, 4383 and 8415 million m^3 in a wet (1997), medium (1999) and dry (2005) year, respectively (see Fig. 1).

Considering the period 1997-2005, net virtual water «imports» show a positive trend, as illustrated in Fig. 1, reaching the highest value in year 2005. Nonetheless, actual

FIG. 1. *Average virtual water «imports» and «exports» through grain trade (Mm^3/year)*



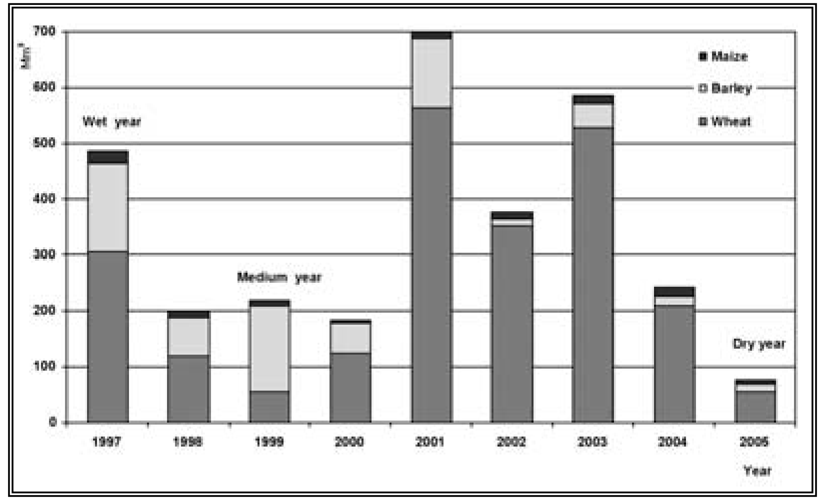
Source: Own elaboration.

values can be located both below and above the trend. Oscillations are likely to be related to climatic parameters. So far, it is difficult to obtain proper estimates and quantify the impact of both effects over net virtual water «imports». Nevertheless, it can be appreciated that the gap between the trend line and the actual value is broader in dry years (see year 2005). To a large extent, this might be explained by lower rainfall and the fact that grain production is heavily dependent on green water availability.

Grain trade is apparently consistent with relative water scarcity since net imports increase in dry years, as 2005, and decrease in wet years, as 1997. However, a disaggregated crop analysis reveals that there isn't such an obvious relation between net virtual water «imports» of wheat and its virtual water content. Wheat accounts for 60% of virtual water «imports» and is mainly cultivated under rainfed conditions. Therefore, its virtual water content tends to be lower in years with lower rainfall level. It could be expected that net virtual water «imports» through wheat trade were higher in years with lower virtual water content. However, our calculations do not always fit with this reasoning. Other factors, such as the demand for a homogeneous product or specific quality for the agro-food industry, have a direct influence on crop trade. Therefore, the notion of virtual water applied to international trade does not always provide a clear representation of water use efficiency. And yet, it gives a broad picture of how water resources are «shifted» among countries as a result of trade relations and provides a new insight on how water resources are allocated.

Special political relations among Mediterranean countries, reflected in specific agreements of organizations such as Barcelona Declaration or Euro-Mediterranean partnership, could be the main trade drivers of Spanish virtual water «exports» through grain trade. As nearly 60% of virtual water

FIG. 2. *Average green virtual water «exports» by type of grain and year (Mm^3/year)*



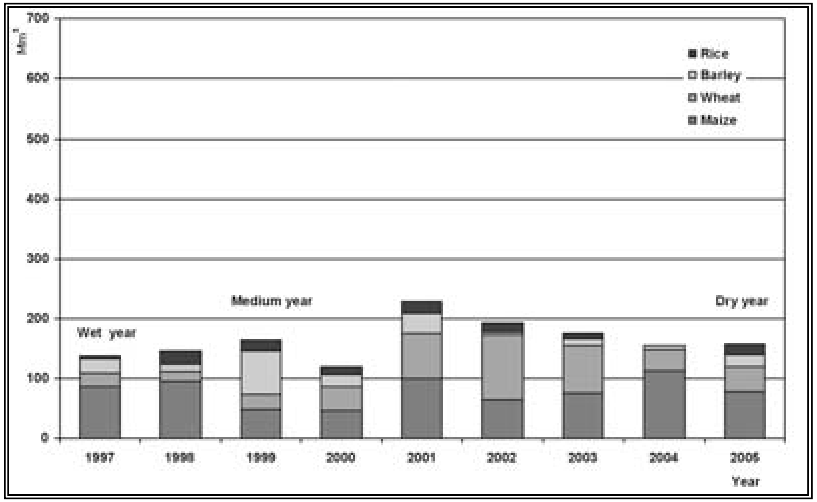
Source: Own elaboration.

«exports» take place within the Mediterranean area. In general terms, green virtual water «exports» are higher than blue virtual water «exports». Although in year 2005, this relationship is reversed. Fig. 2 reports the volume of green virtual water «exported» through grain. As it is shown, wheat and barley account for nearly 90% of green virtual water «exports».

Rainfed production represents nearly 64% of total grain production. Therefore, green virtual water «exports» fluctuate to a great extent with climatic conditions. Even though trade patterns do not depend only on climatic parameters, differences might exist due to variations in both quantity traded and crop yielded, as well as in agricultural and trade policies.

Fig. 3 shows that maize and barley are the major blue virtual water «exporters». As it was mentioned before, trade

FIG. 3. *Average blue virtual water «exports» by type of grain and year (Mm^3/year). Blue water valued at its shadow price*



Source: Own elaboration.

on these commodities might be mainly related to market proximity and location, as well as to special trading partnerships. Regarding blue water consumption, it is interesting to highlight the case of rice production. Although rice accounts for 20% of blue water consumption in grain production, production and trade are relatively low when compared with other grains. However, rice production in Spain is often linked to specific labelled qualities, as well as to a particular landscape.

International trade in maize and barley allows for global water «savings», measured as a difference in virtual water content between Spain and its trade partners. By contrast, wheat trade does not always «save» water virtually. Water «saving» through wheat trade can be either positive or negative depending on the year. However, national water «savings» are always positive in terms of volume. By

importing grain domestic demand for blue and green water is reduced. Furthermore, it should be noted that, from an economic perspective, «saving» water involves a reallocation of water from low added value to high added value activities. In this sense, green water «savings» are economically insignificant. However, «saving» green water might be environmentally relevant because of the obvious nexus between green water and land resources allocation.

6.2. Economic virtual water «flow»

Blue water value fluctuates according to relative water scarcity. Furthermore, the type of hydrological year and the geographic region also have an influence on scarcity values. It is important to take into account water storage levels in addition to the rainfall level. If the stored volume is high then even if annual rainfall is lower than the average level irrigation with surface water will hardly change. The effects over surface water availability for irrigation and crop yields will be felt after several years with low rainfall levels. In the case of groundwater irrigation, crop water requirements might even be satisfied during drought periods. Nevertheless, this would reduce underground reservoirs and have negative environmental impacts, such as aquifer overexploitation and depletion (e.g. Tablas de Daimiel National Park).

Overall, the blue water national shadow price varies between 0.005 €/m^3 in a wet year and 0.22 €/m^3 in a dry year. These values stand in contrast with both the average (surface) water tariff paid by irrigators in Spain, which equals 0.02 €/m^3 (MMA, 2007b), and the weighted national conveyonce and transportation costs, which are equivalent to 0.08 €/m^3 (ibid.).

Table 4 reports the economic and volumetric blue virtual water «exports» of Spain through grain trade. The economic value of blue water is highly dependent on the level of scarcity. Therefore, this has a direct impact on the economic value of blue water «exchanged». The economic scarcity value of blue virtual water «exports» oscillates between 0.7 and 34.2 million Euros for a wet (1997) and dry (2005) year, respectively. Valuing blue water at the average water tariff paid by irrigators in Spain blue virtual water «exports» oscillates between 2.8 and 3.3 million Euros for a wet and dry year, respectively. In parallel, if conveyance and transportation costs are considered blue virtual water «exports» fall between 11 and 13 million €. These numbers attest for the relevance of considering the opportunity cost of water resources when assessing virtual water «flows».

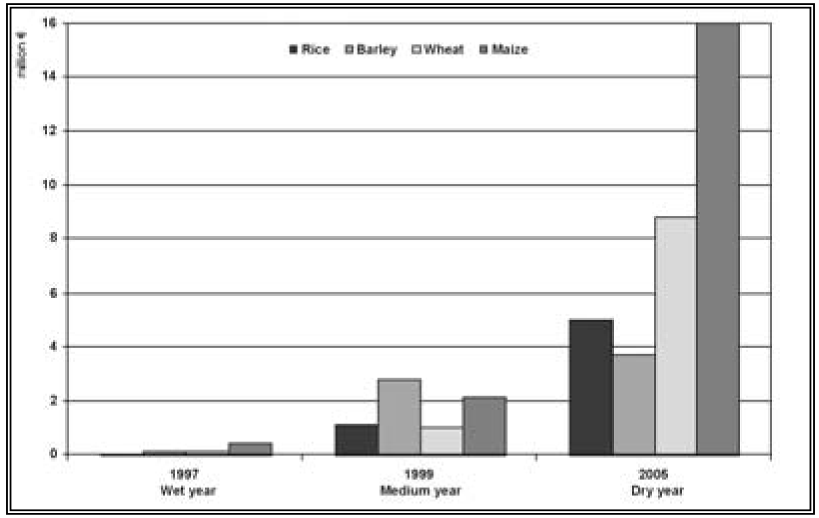
TABLE 4. *Economic (million €) and volumetric (Mm³) blue virtual water «exports» in grain trade*

		Wet year 1997	*Medium year 1999*	*Dry year 2005*
Blue virtual water «exports» (million €)	Weighted shadow price* (0.005/0.04/0.22 €/m³)	0,7	7,1	34,2
	Average tariff** (0.02 €/m³)	2,8	3	3,3
	Weighted average distribution cost** (0.08 €/m³)	11	12	13
Blue virtual water «exports» * (Mm³)		139,5	164,3	159,1

Source: *Own elaboration and **MMA(2007b)

Comparing year 2005, considered as a dry year, with year 1999, representative of a medium year, the volume of blue virtual water «exports» decreases by 3%, but its economic value is multiplied by five. These results show the contrast between volumetric and economic blue virtual water «flow». The evolution of exports, measured by weight and volume, is not parallel to variations on resource scarcity, measured in economic terms.

FIG. 4. *Economic blue virtual water «exports» by type of grain (million €/year). Blue water valued at its shadow price*



Source: Own elaboration.

In terms of volume, wheat is the major virtual water «exporter», as shown in Fig. 4. However, since wheat exports are overwhelmingly «green-water» the economic or scarcity value is lower than in crops such as maize or barley. The scarcity value of blue virtual water «exports» rise with drier years, since both the demand for blue water and the scarcity value increase. Therefore, the economic estimation of economic «flows» provides a deeper insight into crop production and trade relations, complementing the volumetric quantifications. In order to integrate the notion of virtual water into policy design it is essential to consider both volumetric and economic estimates. A comprehensive analysis would also require considering other socioeconomic indicators linked to the multifunctionality of agriculture. However, this is out of the scope of the present study.

As it was previously stated, international grain trade nay reduce the demand for scarce water resources. However, whether this strategy is economically optimal will depend on whether water opportunity cost is properly internalized. From an economic point of view, the key point lies in allocating scarce water resources to those activities which generate greater added value. In this sense, water «saving» is defined from an economic perspective. The environmental impacts of trade might also be addressed by considering the economic value of virtual water «flows». Based on this, water and trade policies could be enhanced by integrating environmental concerns in both importing and exporting countries.

7. CONCLUSION

Virtual water evaluates the volume of green and blue water «transferred» through international trade. In this sense, virtual water addresses production location as well as consumption and trade patterns. From a theoretical point of view, virtual water «flows» contribute to enhancing water and food security in arid and semiarid countries.

Our calculations show that virtual water content is highly sensitive to several key data. This is highlighted by comparing our results with those previously estimated by Chapagain and Hoekstra (2004). The major difference lies on the distinction between blue and green water, as well as on the spatial and time dimensions that we have considered in our analysis. While Chapagain and Hoekstra (ibid.) referred their calculations to the FAO's climatic database ClimWat, this study approaches the estimations at regional level (Autonomous Community) for the period 1997-2005. Furthermore, when assessing crop virtual water «flows» it is essential to consider, on the one hand, virtual water content values in the specific production context, and on the other hand, the blue and green components of virtual water.

One step further on virtual water studies requires also taking into consideration economic data related to water issues. The present study addresses blue virtual water «exports» from both volumetric and economic perspectives. Regarding the economic value of blue water it is essential to consider the real scarcity value, as shown by the gap between the actual average water tariff and the correspondent shadow price or scarcity value. Therefore, the real opportunity cost of water should be reflected in trade patterns in order to obtain real estimates of gains from international trade.

Spain is a net grain virtual water «importer», mainly through wheat and maize trade. The volume of net virtual water «imports» amount to 3420, 4383 and 8415 million m^3 in a wet (1997), medium (1999) and dry (2005) year, respectively. Therefore, grain trade is apparently consistent with relative water scarcity as net imports increase in dry years. However, the evolution of grain exports, expressed as a variation in quantity and volume, does not match the variations on resource scarcity. A disaggregated crop analysis reveals that there are other factors, such as quality, product specialization or the demand for a standardized product, which also influence trade decisions and are not included in the notion of virtual water. The analysis of international trade from a virtual water perspective is useful to raise awareness over water resources and water management. However, it provides inaccurate conclusions to perform a comprehensive analysis of specific trade patterns, especially in those cases where quality specialization or the opportunity cost of other factors might be as relevant as water scarcity.

Although the notion of virtual water does not provide unambiguous conclusions about international trade efficiency from a water resources perspective, it might foster cooperation among countries for improving water and land management globally. This is especially relevant when considering adaptation to climate change together with production and consumption patterns. Virtual water could therefore encourage discussions on transboundary water resource management strategies.

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