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Article

The Spanish Food Industry on Global Supply Chains and Its Impact on Water Resources

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Abstract: The study of the impact of economic activities on natural resources through global supply chains is increasingly demanded in the context of the growing globalization of economies and product fragmentation. Taking Spain as a case study and a sector with significant economic and environmental impacts, the agri-food industry, the objective of this work is two-fold. First, we estimate the associated water impact, both from the production and consumption perspectives, paying special attention to the water embodied in production exchanges among countries and sectors. To that aim, we use an environmentally-extended multiregional input-output model (MRIO). Second, we assess the main driving factors behind changes in direct and embodied water consumption between the years 1995 and 2009 by means of a structural decomposition analysis. The MRIO model provides a comprehensive estimate of the economic linkages among regions and economic sectors and, therefore, allows calculating the environmental impacts over international value chains. The results indicate that the food industry exerts large impacts on global water resources, particularly given the remarkable interactions with the domestic and foreign agricultural sectors, These growing linkages show how consumption patterns, and, therefore, lifestyles, involve large environmental impacts through the whole and global supply chains.

Keywords: food industry; water; demand; trade; technology; input-output

1. Introduction

Although the world currently produces enough food for its citizens, there exist large disparities in the access to food across regions and income levels [1,2]. Food security has been declared as a key challenge to be faced in the near future by many international institutions. In this line, the United Nations [3] states that "the food and agriculture sector offers key solutions for development, and is central for hunger and poverty eradication". Moreover, the European Commission [4] says that "the challenge is how to meet consumers' needs and preferences while minimizing the related impact on health and the environment".

Several studies [5,6] point at water scarcity, climate change, crop yields, the level of investment or the AIDS epidemic as some of the factors conditioning the achievement of one of the Millennium Development Goals (MDGs), the eradication of poverty and hunger [7]. In the path towards food security, two sectors stand out as essential in all economies: agriculture and the food industry. It has been proven that economic development is associated with increases in the food supply, as well as with dietary changes that lead to the improvement of the nutritional status of countries [8,9]. Moreover, these changes usually happen together with qualitative variations in the production, processing, distribution and marketing of food, *i.e.*, with the development of the food industry [9]. In this line, there are studies that state that as countries develop, they tend to increase the share of the food and beverage industries on GDP. Then, this sector seems to maintain a high share in the economy across different levels of GDP per capita [10].

Globalization has increased the level of interdependence of the regional food industries and has consequently raised concerns on its impact, not only on the economies, but also on the environment. Today, we find a vast literature examining the water footprint of countries, studying the impact that trade patterns and domestic consumption has on water resources [11–13]. Food security and the global water crisis seem to be increasingly linked, since local shortages can become global through international supply chains and threaten global food security. Thus, in this paper, we focus on the impact of the growing integration of the food industry on water resources. More concretely, our main objective is to study the impact of the food industry on water resources through its activity on global supply chains, paying special attention to the interactions with other domestic and foreign sectors.

Focusing in a semi-arid country, Spain, we analyze the trends on the water consumed by this sector between 1995 and 2009. To that aim, we examine the forward and backward linkages with the rest of economic sectors in Spain and with all of the sectors in other countries in the world using an environmentally-extended multiregional input-output model.

According to the statistical classification of economic activities in the European Community NACE revision 2, the food industry involves the processing of the products of agriculture into food, dealing with different kinds of products: meat, fish, fruit and vegetables, fats and oils, milk products, grain mill products and other food products. The food industry in Spain is the first industrial sector, accounting for 20.5% of net sales, 18.4% of employed people and 15.1% of value added in 2012 (Spanish Ministry of Agriculture and the Industrial Companies Survey [14]). Thus, we analyze one of the main sectors generating industrial income and employment in Spain, presenting important backward linkages with the agricultural sector [15].

This article contributes to the existing literature on the food industry sustainability [16–18] by offering a general overview of the situation, trends, interrelations and explaining factors lying behind the water consumption of this key sector. Our model offers a comprehensive assessment of the food industry, allowing identifying the intermediate and final demands, the level of integration of the sectors and countries, as well as the responsibilities of production and consumption. This analysis shows a growing separation of the production and consumption sides of the food industry with relevant impacts on domestic and foreign water resources.

We use an environmentally-extended multiregional input-output (MRIO) model to estimate the volume of water embodied in the domestic and traded production of the Spanish food sector. Subsequently, we apply a structural decomposition analysis (SDA), which enables measuring the contribution of water intensity changes, technological changes or variations in the level of demand to the pattern followed by water consumption.

The article is organized as follows. Section 2 explains the materials and the method used and is divided into two parts. First, Section 2.1 describes the data sources used. Then, Section 2.2 presents the methodology utilized in the paper. Section 3 analyzes and discusses the main results in the paper, and the paper closes with the main conclusions in Section 4.

2. Materials and Methods

2.1. Materials

The World Input Output Database (WIOD) is the main data source of this study. Firstly, the multiregional input-output (MRIO) table has been taken from WIOD and offers information on the economic interrelations among 35 economic sectors in 40 countries and a region called the "Rest of the World" (ROW) during the period 1995 to 2009 (see [19,20] for more information on the methodology). WIOD offers MRIO tables expressed in current monetary units and in previous year prices. Hence, we deflate the 2009 table, expressing it in constant 1995 prices.

Note that given the importance of agriculture on the total water consumption of countries and the large linkages with the food industry, we have disaggregated this sector into thirteen additional groups of products (animals, cereals, vegetal fibers, fruits and nuts, dairy products and eggs, oil crops, pulses, roots and tubers, spices, stimulants, sugar crops, tobacco, vegetables). Our starting point is the WIOD table, the detailed agricultural information on production provided by the Food and Agriculture Organization Corporate Statistical Database (FAOSTAT) [21] and the detailed information on trade provided by the United Nations Commodity Trade Statistics Database (COMTRADE) [22]. We have to match these statistical sources, providing disaggregation criteria common to all of the countries. In the first step, we obtain information on the share of each group in the domestic production from FAOSTAT [21] and foreign trade from COMTRADE [22]. Then, we disaggregate agriculture in the MRIO tables. The share of the different products on agricultural production is used to proportionality disaggregate the rows and columns of domestic intermediate agricultural inputs (except for the relationships between the new created sectors), the final demand of agricultural products, as well as the agricultural value added and total output. A restrictive assumption in this process is that the newly-created agricultural sectors do not trade amongst themselves, either domestically or internationally. Comparing with the situation of no disaggregation, although this assumption could result in being very restrictive for an in-depth analysis of the agrarian sector and the associated subsectors, it has no significant effect on the water embodied by the food sector in Spain, offering additional information on a specific link: the water used in the agrarian sector and embodied in the goods of the food sector. In any case, given these assumptions, caution is needed for interpreting specific sub-sectorial results. As a result, we obtain a MRIO table with 47 sectors and 41 countries. Finally, it was necessary to apply the GRAS adjustment, given the mismatch between the sum of the totals in rows and columns. Basically, the GRAS adjustment is a generalization of RAS proposed by Junius and Oosterhaven [23] and improved by Lenzen *et al.* [24] that allows working with matrices containing positive and negative values.

To obtain the environmentally (water)-extended MRIO model, we also need data on the water consumed per sector and country. Water intensities per sector and country, *i.e.*, direct water consumption per unit of product per sector and country, have been taken from the WIOD database in the case of the industrial sectors. We use the information regarding green, blue and grey water. According to Hoekstra *et al.* [25], green water is "the precipitation on land that does not run off or recharge the groundwater but is stored in the soil or temporarily stays on top of the soil or vegetation", blue water refers to "fresh surface and groundwater" and grey water is "the volume of freshwater that is required to assimilate the load of pollutants based on existing ambient water quality standards".

As the environmental sources of WIOD [26] indicate, the water consumption of industrial sectors given by Mekonnen and Hoekstra [13] is distributed to WIOD sectors according to the share of water use in the EXIOPOL database [27]. For the agricultural groups, we have directly estimated the water intensities from the detailed and disaggregated information given by [28,29]. To our knowledge, there is not any other international and multisectoral database that fits water data with national accounting. Thus, despite its drawbacks (to which we well refer later), the environmental WIOD database is particularly relevant.

2.2. Methods

Methodologically, we depart from Equation (1), where total output is obtained as the sum of demand for intermediate inputs and final demand in a multiregional framework:

$$\mathbf{x} = \mathbf{A}\mathbf{x} + \mathbf{y} \tag{1}$$

with $\mathbf{x}$ representing the total output of each sector, $\mathbf{A}$ being the technical coefficients matrix and $\mathbf{y}$ the total final demand by sector. Following Leontief [30], the output can be expressed as the product between the Leontief inverse and the final demand, which yields:

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} = \mathbf{L}\mathbf{y} \tag{2}$$

This equilibrium equation can be environmentally-extended (Equation (3)) in order to consider the effect of economic activity on natural resources (*i.e.*, water), showing the volume of water embodied in domestic and traded production in every country and sector in the MRIO table for two different periods, t_0 = 1995 and t_1 = 2009. This model allows capturing all of the interrelations among economic sectors and countries in the global economy and, therefore, studying the actual water consumption of the food industry, regardless the origin of water resources. To that aim, we obtain matrix $\mathbf{\Omega}$ for t_0 and t_1 as follows:

$$\begin{bmatrix} \mathbf{\Omega}_{1,1} & \mathbf{\Omega}_{1,2} & \cdots & \mathbf{\Omega}_{1,41} \\ \mathbf{\Omega}_{2,1} & \mathbf{\Omega}_{2,2} & \cdots & \mathbf{\Omega}_{2,41} \\ \cdots & \cdots & \cdots & \cdots \\ \mathbf{\Omega}_{41,1} & \mathbf{\Omega}_{41,2} & \cdots & \mathbf{\Omega}_{41,41} \end{bmatrix} = \begin{bmatrix} \hat{\mathbf{w}}_{1,1} & 0 & 0 & 0 \\ 0 & \hat{\mathbf{w}}_{2,2} & 0 & 0 \\ 0 & 0 & \cdots & 0 \\ 0 & 0 & 0 & \hat{\mathbf{w}}_{41,41} \end{bmatrix} \begin{bmatrix} \mathbf{L}_{1,1} & \mathbf{L}_{1,2} & \cdots & \mathbf{L}_{1,41} \\ \mathbf{L}_{2,1} & \mathbf{L}_{2,2} & \cdots & \mathbf{L}_{2,41} \\ \cdots & \cdots & \cdots & \cdots \\ \mathbf{L}_{41,1} & \mathbf{L}_{41,2} & \cdots & \mathbf{L}_{41,41} \end{bmatrix} \begin{bmatrix} \hat{\mathbf{Y}}_{1,1} & \hat{\mathbf{Y}}_{1,2} & \cdots & \hat{\mathbf{Y}}_{1,41} \\ \hat{\mathbf{Y}}_{2,1} & \hat{\mathbf{Y}}_{2,2} & \cdots & \hat{\mathbf{Y}}_{2,41} \\ \cdots & \cdots & \cdots & \cdots \\ \hat{\mathbf{Y}}_{41,1} & \hat{\mathbf{Y}}_{41,2} & \cdots & \hat{\mathbf{Y}}_{41,41} \end{bmatrix} \quad (3)$$

where $\mathbf{\Omega}_{r,s}$ are the matrices of the volume of water used in production activities in region *r* to support the final demand in region *s*; $\hat{\mathbf{w}}_{r,r}$ are diagonal matrices of direct water coefficients that indicate the volume of water necessary to produce a unit of product in each country *r*; $\mathbf{L}_{r,s}$ are the Leontief inverse matrices; and $\hat{\mathbf{Y}}_{r,s}$ are diagonalized matrices of final demand that show the volume of final goods that every sector in s gets from each sector in *r*. On the one hand, summing by rows in matrix $\mathbf{\Omega}$, *i.e.*, $\sum_{\mathrm{r}} \mathbf{\Omega}_{\mathbf{rs}}$, we obtain the embodied water consumption (EW) of country *s* (also known as embodied water), indicating the total water directly and indirectly consumed from each sector and every country *r*, to meet the final demand of *s*. On the other hand, summing by columns, $\sum_{\mathrm{s}} \mathbf{\Omega}_{\mathbf{rs}}$, we get direct water consumption (DW), which measures the volume of water directly consumed in country r to meet the final demand in each country *s*.

Once the global interrelations among economic sectors and countries in the world have been obtained, we focus on the Spanish food industry, trying to determine the effect of its activity on water resources by calculating its embodied and direct water consumption. Hence, we take the row and column corresponding to this sector in Spain from matrix $\mathbf{\Omega}$.

After estimating the effect of the Spanish food sector on water resources, the next step involves determining and quantifying the main drivers behind the changes in its embodied and direct water consumption. To that aim, we apply a structural decomposition analysis (SDA) to measure the driving forces underlying the changes in embodied and direct water in domestic and traded production. SDA separates the change of an aggregated variable into a group of driving forces [31]. In a discrete schema, when we try to measure the changes in the dependent variable between two periods, *t*−1 and *t*, there are different ways of solving this expression by way of exact decompositions, which leads to the well-known problem of the non-uniqueness of the SDA solution. In our case, if decomposition is based on three factors, we can obtain the following *3!* exact decompositions. In practice, as a "commitment solution", the average of all possible solutions is considered. Nevertheless, as is demonstrated in [31], the simple average of the two polar decompositions runs as a good approximation to the average of the *3!* exact forms.

Note that as we proceed with the estimation of water consumption, the SDA is applied to the whole MRIO matrix $\mathbf{\Omega}$, and then, we study the specific case of the Spanish food industry. The first step involves obtaining the changes in $\mathbf{\Omega}$ between t_0 = 1995 and t_1 = 2009.

$$\Delta\mathbf{\Omega} = \mathbf{\Omega}_1 - \mathbf{\Omega}_0 = \hat{\mathbf{w}}_{\mathbf{1}}\mathbf{L}_{\mathbf{1}}\hat{\mathbf{Y}}_{\mathbf{1}} - \hat{\mathbf{w}}_{\mathbf{0}}\mathbf{L}_{\mathbf{0}}\hat{\mathbf{Y}}_{\mathbf{0}} \quad (4)$$

Subsequently, we get the polar decompositions of Equation (4):

$$\Delta\boldsymbol{\Omega} = \Delta\widehat{\mathbf{w}}\mathbf{L_0}\widehat{\mathbf{Y}}_\mathbf{0} + \widehat{\mathbf{w}}_\mathbf{1}\Delta\mathbf{L}\widehat{\mathbf{Y}}_\mathbf{0} + \widehat{\mathbf{w}}_\mathbf{1}\mathbf{L_1}\Delta\widehat{\mathbf{Y}} \tag{5}$$

$$\Delta\boldsymbol{\Omega} = \Delta\widehat{\mathbf{w}}\mathbf{L_1}\widehat{\mathbf{Y}}_\mathbf{1} + \widehat{\mathbf{w}}_\mathbf{0}\Delta\mathbf{L}\widehat{\mathbf{Y}}_\mathbf{1} + \widehat{\mathbf{w}}_\mathbf{0}\mathbf{L_0}\Delta\widehat{\mathbf{Y}} \tag{6}$$

Taking averages of Equations (5) and (6), we obtain Equation (7):

$$\Delta\boldsymbol{\Omega} = \frac{1}{2}\left(\Delta\widehat{\mathbf{w}}\mathbf{L_0}\widehat{\mathbf{Y}}_\mathbf{0} + \Delta\widehat{\mathbf{w}}\mathbf{L_1}\widehat{\mathbf{Y}}_\mathbf{1}\right) + \frac{1}{2}\left(\widehat{\mathbf{w}}_\mathbf{1}\Delta\mathbf{L}\widehat{\mathbf{Y}}_\mathbf{0} + \widehat{\mathbf{w}}_\mathbf{0}\Delta\mathbf{L}\widehat{\mathbf{Y}}_\mathbf{1}\right) + + \frac{1}{2}\left(\widehat{\mathbf{w}}_\mathbf{1}\mathbf{L_1}\Delta\widehat{\mathbf{Y}} + \widehat{\mathbf{w}}_\mathbf{0}\mathbf{L_0}\Delta\widehat{\mathbf{Y}}\right) \tag{7}$$

Hence, from Equation (7), we can obtain the following effects that will be different depending on whether embodied or direct water consumption are analyzed. Firstly, the intensity effect measures the contribution of changes in water intensities to changes in the volume of water consumption. More concretely, regarding embodied water consumption ($\mathrm{IE_{EW}}$), it quantifies the effect of changes in water intensities, both domestic ($\mathrm{IE_{EW\_domestic}}$) and foreign ($\mathrm{IE_{EW\_imported}}$), to variations in the volume of embodied water in total (Equation (8)). In the case of direct water consumption ($\mathrm{IE_{DW}}$), it examines how changes in domestic water intensities affect the volume of water directly consumed by the food Spanish sector (Equation (9)).

$$\begin{aligned}\mathbf{IE_{EW}} &= \frac{1}{2}\left(\Delta\widehat{\mathbf{w}}_\mathbf{dom}\mathbf{L_0}\widehat{\mathbf{Y}}_\mathbf{0} + \Delta\widehat{\mathbf{w}}_\mathbf{dom}\mathbf{L_1}\widehat{\mathbf{Y}}_\mathbf{1}\right) + \frac{1}{2}\left(\Delta\widehat{\mathbf{w}}_\mathbf{imp}\mathbf{L_0}\widehat{\mathbf{Y}}_\mathbf{0} + \Delta\widehat{\mathbf{w}}_\mathbf{imp}\mathbf{L_1}\widehat{\mathbf{Y}}_\mathbf{1}\right) \\ &= \mathbf{IE_{EW\_domestic}} + \mathbf{IE_{EW\_imported}}\end{aligned} \tag{8}$$

$$\mathbf{IE_{DW}} = \frac{1}{2}\left(\Delta\widehat{\mathbf{w}}_\mathbf{dom}\mathbf{L_0}\widehat{\mathbf{Y}}_\mathbf{0} + \Delta\widehat{\mathbf{w}}_\mathbf{dom}\mathbf{L_1}\widehat{\mathbf{Y}}_\mathbf{1}\right) \tag{9}$$

In the second place, the technological effect links changes in the technology of production with changes in water consumption. Specifically, concerning embodied water consumption ($\mathrm{TE_{EW}}$), it identifies to what extent variations of the technology of production through the whole supply chain affect the volume of embodied water (Equation (10)). It is decomposed into the domestic technological effect ($\mathrm{TE_{EW\_domestic}}$), which calculates the impact of changes in inputs produced domestically to embodied water consumption, and into the backward technological effect ($\mathrm{TE_{EW\_backward}}$), which quantifies the way that changes in technologies of other countries affect the volume of embodied water. If we look at direct water consumption, the technological effect ($\mathrm{TE_{DW}}$) measures the impact of variations in the way of production of intermediate inputs (Equation (11)). It can also be put into the domestic technological effect ($\mathrm{TE_{DW\_domestic}}$), which quantifies the impact of changes in the domestic technology that is utilized domestically, and into the forward technological effect ($\mathrm{TE_{DW\_forward}}$), which assesses the effect of variation in domestic technology that is exported to other countries.

$$\mathbf{TE_{EW}} = \frac{1}{2}\left(\widehat{\mathbf{w}}_\mathbf{1}\Delta\mathbf{L}\widehat{\mathbf{Y}}_\mathbf{0} + \widehat{\mathbf{w}}_\mathbf{0}\Delta\mathbf{L}\widehat{\mathbf{Y}}_\mathbf{1}\right) = \mathbf{TE_{EW\_domestic}} + \mathbf{TE_{EW\_backward}} \tag{10}$$

$$\mathbf{TE_{DW}} = \frac{1}{2}\left(\widehat{\mathbf{w}}_\mathbf{1}\Delta\mathbf{L}\widehat{\mathbf{Y}}_\mathbf{0} + \widehat{\mathbf{w}}_\mathbf{0}\Delta\mathbf{L}\widehat{\mathbf{Y}}_\mathbf{1}\right) = \mathbf{TE_{DW\_domestic}} + \mathbf{TE_{DW\_forward}} \tag{11}$$

Finally, the scale effect is used to explain water consumption trends on the basis of the changes in the volume of the final demand. Particularly, as for embodied water consumption ($\mathrm{SE_{EW}}$), it computes the effect of changes in the final demand of the country of reference (Equation (12)). It is divided into final demand for goods produced domestically ($\mathrm{SE_{EW\_domestic}}$) and final demand for imported products ($\mathrm{SE_{EW\_imported}}$). In terms of direct water consumption, the scale effect ($\mathrm{SE_{DW}}$) calculates the impact of changes in the level of demand, both domestic ($\mathrm{SE_{DW\_domestic}}$) and foreign ($\mathrm{SE_{DW\_foreign}}$).

$$\mathbf{SE_{EW}} = \frac{1}{2}\left(\hat{\mathbf{w}}_1\mathbf{L}_1\Delta\hat{\mathbf{Y}}_{\mathbf{dom}} + \hat{\mathbf{w}}_0\mathbf{L}_0\Delta\hat{\mathbf{Y}}_{\mathbf{dom}}\right) + \frac{1}{2}\left(\hat{\mathbf{w}}_1\mathbf{L}_1\Delta\hat{\mathbf{Y}}_{\mathbf{imp}} + \hat{\mathbf{w}}_0\mathbf{L}_0\Delta\hat{\mathbf{Y}}_{\mathbf{imp}}\right) = \mathbf{SE_{EW\_domestic}} + \mathbf{SE_{EW\_imported}} \quad (12)$$

$$\mathbf{SE_{DW}} = \frac{1}{2}\left(\hat{\mathbf{w}}_1\mathbf{L}_1\Delta\hat{\mathbf{Y}}_{\mathbf{dom}} + \hat{\mathbf{w}}_0\mathbf{L}_0\Delta\hat{\mathbf{Y}}_{\mathbf{dom}}\right) + \frac{1}{2}\left(\hat{\mathbf{w}}_1\mathbf{L}_1\Delta\hat{\mathbf{Y}}_{\mathbf{foreign}} + \hat{\mathbf{w}}_0\mathbf{L}_0\Delta\hat{\mathbf{Y}}_{\mathbf{foreign}}\right) = \mathbf{SE_{DW\_domestic}} + \mathbf{SE_{DW\_foreign}} \quad (13)$$

2.3. Uncertainties

The uncertainties in this study can stem from the Input-output (IO) approach, the data used, as well as the SDA. Firstly, environmentally-extended multiregional input-output models have proven their capability to represent the production generated along the supply chain, the sectoral linkages within the national economies and between suppliers and consumers of different countries and the impact on the natural resources (e.g., water consumption) of these activities [32]. However, results from input-output models present uncertainties, previously discussed in the literature. According to Lenzen *et al.* [33] and Wiedman [34], uncertainties in input-output arise from a variety of sources: data reliability (source data sampling and reporting errors), the assumption of the proportionality between monetary and physical flows or aggregation of different products and producers in a single sector (*i.e.*, homogeneity assumptions), among others. The assumption of homogeneity can result in being especially unrealistic for the agricultural sector. The fixed coefficients production function, implicit in the Leontief model, has often been criticized, since it does not allow for input substitution when relative prices change. More flexible functional forms have been suggested in the field of general equilibrium models. These assumptions could result in being especially problematic for predicting technical changes or for designing realistic scenarios about the future, which is beyond the scope of this article. Moreover, a more realistic description of the agricultural sector has been introduced in the database by considering thirteen groups of agricultural products, both in the definition of water intensities and in the disaggregation of MRIO tables. However, additional research is needed to provide a more accurate representation of agriculture and agricultural technology across different countries and international databases more focused on the agricultural sector; the Global Trade Analysis Project (GTAP database), for example, could be helpful in this line.

Secondly, regarding water data, they are provided at the national level, ignoring the specificities of water consumption and water availability at the local level. In this line, Wiedmann *et al.* [34] indicate that "spatially explicit impact assessment models are required to locate environmental impacts below the sub-national level (e.g., local water use)". Similarly, Hoekstra *et al.* [25] and Tillotson *et al.* [35] pointed to the need to further assess accuracy, develop databases and address uncertainties on the water footprint information. Several studies [36–38] have recently quantified the uncertainties on water coefficients. For the particular case of Spain, Garrido *et al.* [39] point out that the coefficients in [29] result in an overestimation of the results of the water footprint when differentiating between irrigated and rainfed products. We distinguish among the green, blue and grey water consumption of the Spanish food industry.

Finally, we must consider the uncertainty referring to the non-uniqueness problem of the SDA methodology. The SDA presented in Equation (7) is an exact decomposition; however, it is possible to get other decompositions by simply changing the order of the determinants. As Dietzenbacher and

Los [31] note, the different expressions could obtain quite different contributions to the total change for the same factor. The average of the polar solutions, used in this study, has been accepted as a good alternative to empirically deal with this issue [31].

3. Results and Discussion

The agri-food sector is a relevant industry with positive economic effects in Spain, highlighting its capacity to generate income and employment in rural areas and its strong linkages with other activities, especially with the agrarian sectors, which mainly provide their inputs. Nonetheless, given its important relationship with agrarian activity, the main direct consumer of water in Spain (which represents more than 80% of the direct consumption of water), it is very important to assess the environmental impacts of this key sector, especially regarding the impact on water resources. As can be seen in Table 1, on average, the food industry in Spain entails about 30% of the water embodied in the Spanish final demand. That is, this sector is responsible for about one third of the water consumed worldwide to meet the Spanish final demand. Studying this sector deeply is therefore essential to determine its effect in terms of domestic and foreign water resources.

Table 1. Water embodied in the Spanish final demand, million m^3.

Embodied water	**1995**			**2009**		
	Blue	**Green**	**Grey**	**Blue**	**Green**	**Grey**
Spain (million m^3) (a)	56,491	307,397	39,192	57,804	311,016	42,846
Agri-Food Spanish sector (million m^3) (b)	17,140	108,170	13,184	15,572	104,224	12,505
(a)/(b) %	30	35	34	27	34	29

As Table 2 shows, the embodied water (water consumption measured from the consumer responsibility) of the food sector is much higher than direct water consumption (water consumption measured from the producer responsibility) for green, blue and grey water. This basically means that the effect exerted by the food industry on water resources is not shown by its direct water consumption, making a comprehensive analysis of the water consumed by this sector through the whole global supply chain necessary. That way, in order to assess the actual impact of this relevant sector on foreign water resources and on the Spanish water ecosystems, it is crucial to study its interrelations and linkages among countries and sectors all over the world. As an example, over 25% of the water finally crystallized in the Spanish food products is consumed in other countries and another 74% comes from other domestic sectors, embodied mostly in agricultural products.

Table 2. The impact of the Spanish food industry on water resources, 1995–2009 (million m^3).

Impact of the food industry	1995			2009			1995–2009		
	Blue	Green	Grey	Blue	Green	Grey	Blue	Green	Grey
Producer responsibility /Direct water consumption	41.0	0.0	0.0	49.4	0.0	0.0	8.4	0.0	0.0
Consumer resp./Embodied water consumption	17,140	108,170	13,184	15,572	104,224	12,505	−1569	−3946	−679
Producer responsibility—Consumer responsibility	−17,099	−108,170	−13,184	−15,522	−104,224	−12,505	1577	3946	679
Direct water consumption of the agri-food sector	23.8	0.0	0.0	25.5	0.0	0.0	1.7	0.0	0.0
Water embodied in exports to other countries	2899	17,092	2145	4243	25,493	3171	1344	8401	1026
Water embodied in imports from other countries	3252	30,879	3282	4350	43,242	4632	1098	12,363	1350
Foreign net balance (WEX-WEM)	−353	−13,787	−1137	−107	−17,749	−1461	246	−3962	−324
Water embodied in sales to other Spanish sectors	15.8	0.0	0.0	21.7	0.0	0.0	5.9	0.0	0.0
Water embodied in purchases from other Spanish sectors	16,762	94,383	12,047	15,437	86,475	11,044	−1325	−7908	−1004
Domestic net balance (WEDS-WEDP)	−16,747	−94,383	−12,047	−15,415	−86,475	−11,044	1331	7908	1004

Notes: WEX: Water embodied in exports; WEM: Water embodied in imports; WEDS: Water embodied in domestic sales; WEDS: Water embodied in domestic purchases.

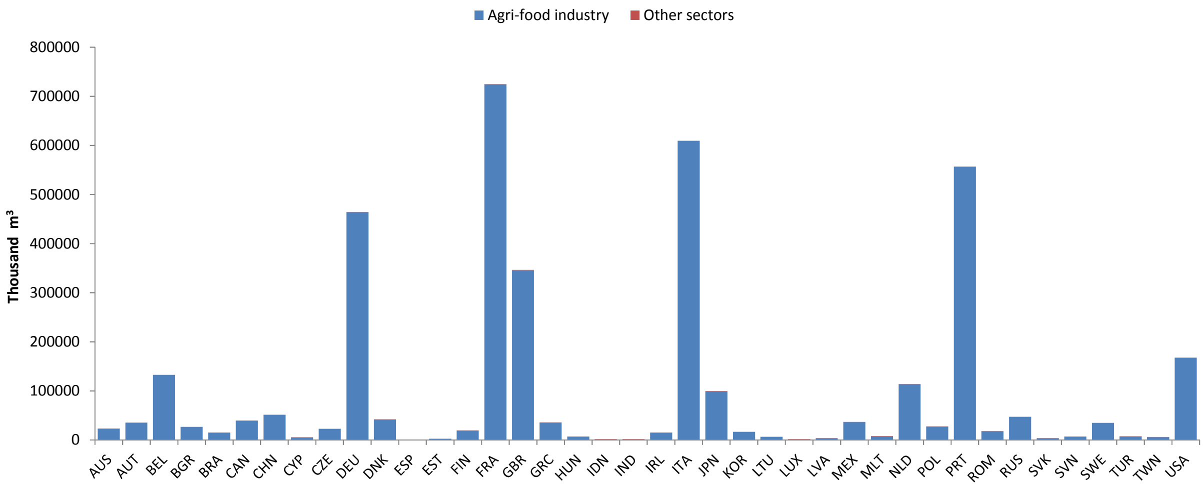
Despite the fact that the direct water consumption of the Spanish food sector can be considered limited, the volume of water embodied in exports and imports of these products to the rest of the world, as well as the exchanges of embodied water with other domestic sectors is really significant. Table 2 shows that the Spanish food industry exported in its products about 2899, 17,092 and 2145 million m^3 of blue, green and grey water, respectively, in 1995. These volumes notably increased between 1995 and 2009, growing yearly at an average growth rate higher than 2.5%. Green water displayed not only the largest absolute increase (8401 million m^3), but also the most rapid average annual growth (3%). In 1995, over 90% of water embodied in exports was a direct consequence of the exports of final food products produced with inputs from other Spanish sectors (see Table S1). Besides, the remaining Spanish food exports (about 10%) also consisted of outputs that were produced domestically, but using inputs coming from abroad. In 2009, the pattern was quite similar; however, the share of water embodied in exports produced with foreign inputs increased, chiefly in the case of green water.

As seen in Figure 1 (and in Figures S1 and S2), the food industries in France, Italy, Portugal or Germany were the main destination of water embodied in Spanish water exports, both in 1995 and 2009. Some of the flows experienced a great increase during these years; this is the case of exports to Bulgaria, Romania, Lithuania, Latvia, Hungary, China and India, which increased more than seven-fold. On the contrary, exports of water embodied in food products to countries, such as Australia, Japan, Brazil, the USA and Turkey, tended to decrease. This can be seen for all colors of water.

Concerning imports, they went from 3252 million m^3 of blue water, 30,879 of green water and 3282 of grey water in 1995 to 4350, 43,242 and 4632 million m^3 of blue, green and grey water in 2009, respectively. On the whole, in 1995, more than 50% of water came embodied in final food output from abroad. This percentage increased by 2009 accounting for about 65%, regardless of the color of water examined. This means a sort of delocalization of impacts, increasing the pressure on other countries induced by the Spanish food products. About 35% of water was also imported, embodied in inputs to produce final outputs that were domestically consumed in 1995. By 2009, these imports represented 25% on total water embodied in imports. Besides, Spain also imported water through inputs used in the food industry that were re-exported, representing around 7% on total water embodied in imports by 1995 and 9% in 2009 (see Table S1).

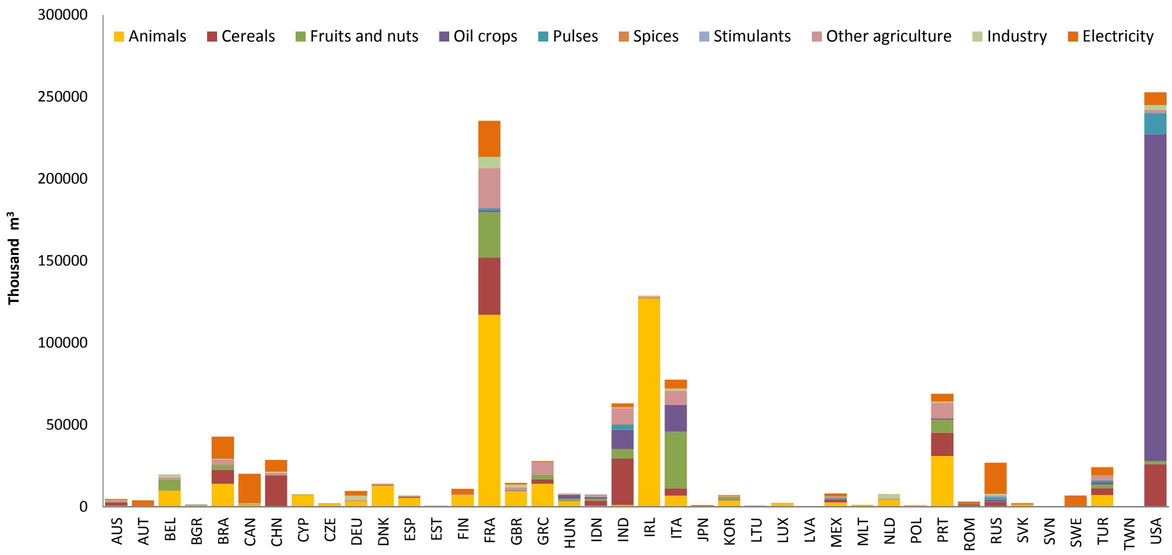
As we can see in Figure 2, in 1995, Spain tended to import blue water mostly from the USA and France. The former provided blue water embodied chiefly in oil crops; however, the latter did it by means of animals, cereals, fruits and nuts, other agricultural products or even the electricity sector. Ireland can also be highlighted as a provider of blue water to Spain by means of animals. The picture seems to be quite different in 2009. Despite that the Spanish food sector kept on obtaining water mostly from the farming sector in France and other agricultural sectors, Spain reduced its blue water imports from the USA. In return, Ireland notably increased its share in the food water imports, transferring mostly water through animals. The same happened with Portugal, which more than doubled its virtual blue water exports to the food industry in Spain. In this period, Spain also obtained large volumes of water embodied in cereals and the electricity sector in China, as well as in cereals and oil crops from India and Romania.

(a)



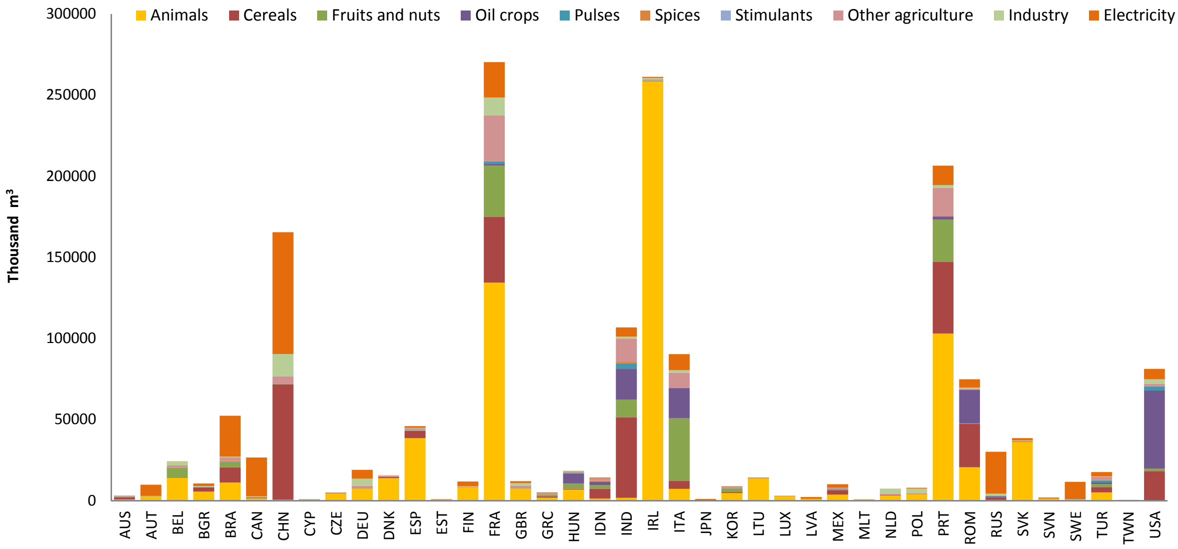
(b)

Figure 1. Blue virtual water exports of the food sector by country and sector in 1995 (**a**) and 2009 (**b**), thousand m^3.



(a)

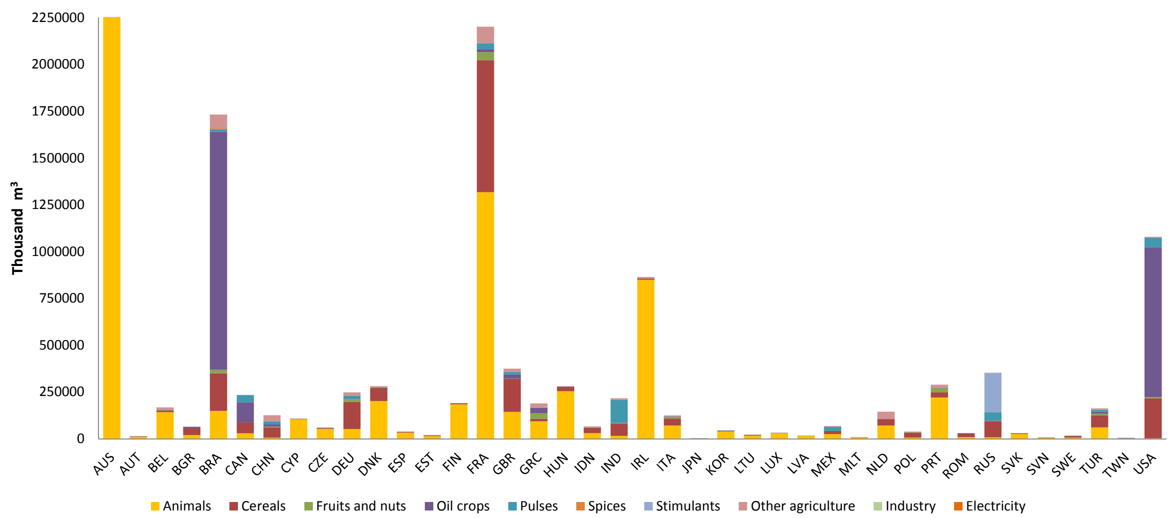
Figure 2. *Cont.*



(**b**)

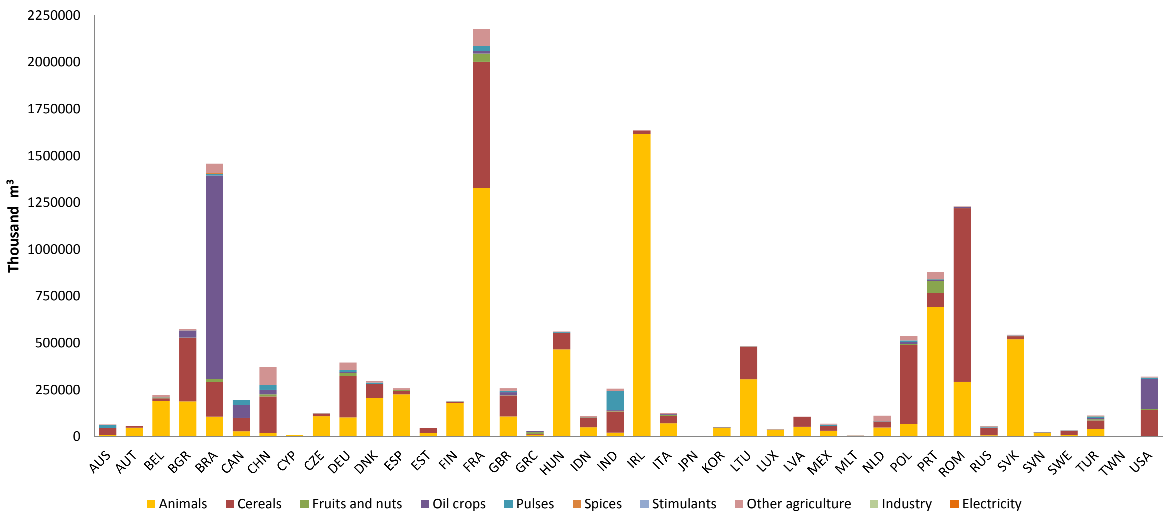
Figure 2. Blue virtual water imports of the food sector by country and sector in 1995 (**a**) and 2009 (**b**), thousand m^3.

Figure 3 shows the pattern of water embodied in imports for green water. In this case, both France and Brazil were the main providers of green water, both in 1995 and 2009. Whereas France exported water embodied in animals and cereals, the Latin American country provided water embodied in oil crops. The share of Brazil for virtual water imports decreased by 2009, but there was an increase in the contribution of countries, such as Ireland, Romania, Portugal and Poland. Displacements of green water from Ireland and Portugal to the Spanish food sector were mainly associated with animal inputs; nevertheless, in the case of Eastern European countries, they were related to cereals used in the Spanish food sector as an important input.



(**a**)

Figure 3. *Cont.*



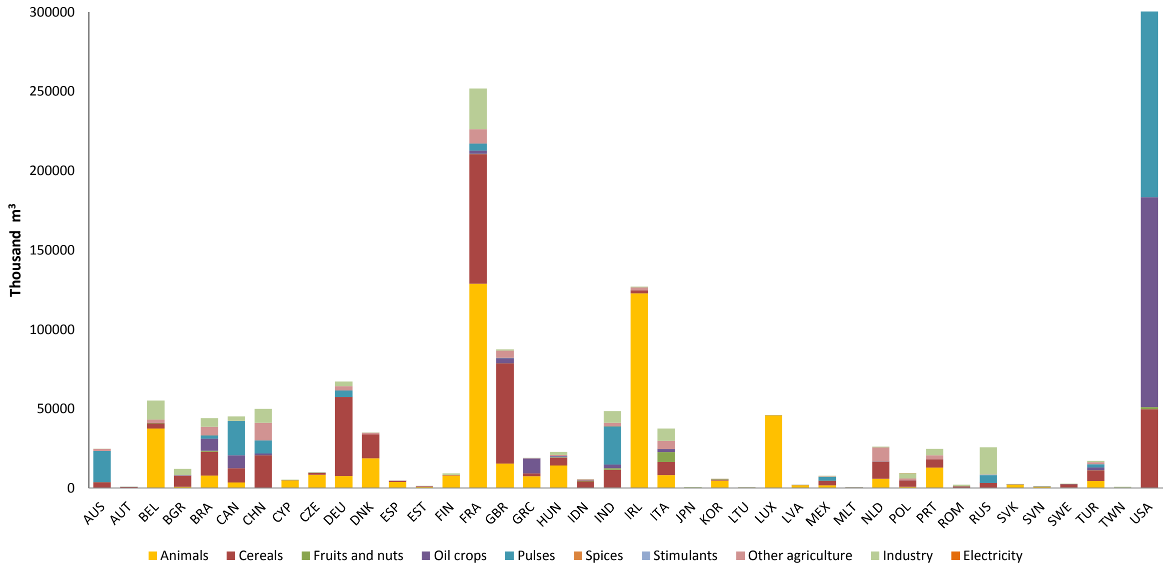
(**b**)

Figure 3. Green virtual water imports of the food sector by country and sector in 1995 (**a**) and 2009 (**b**), thousand m^3.

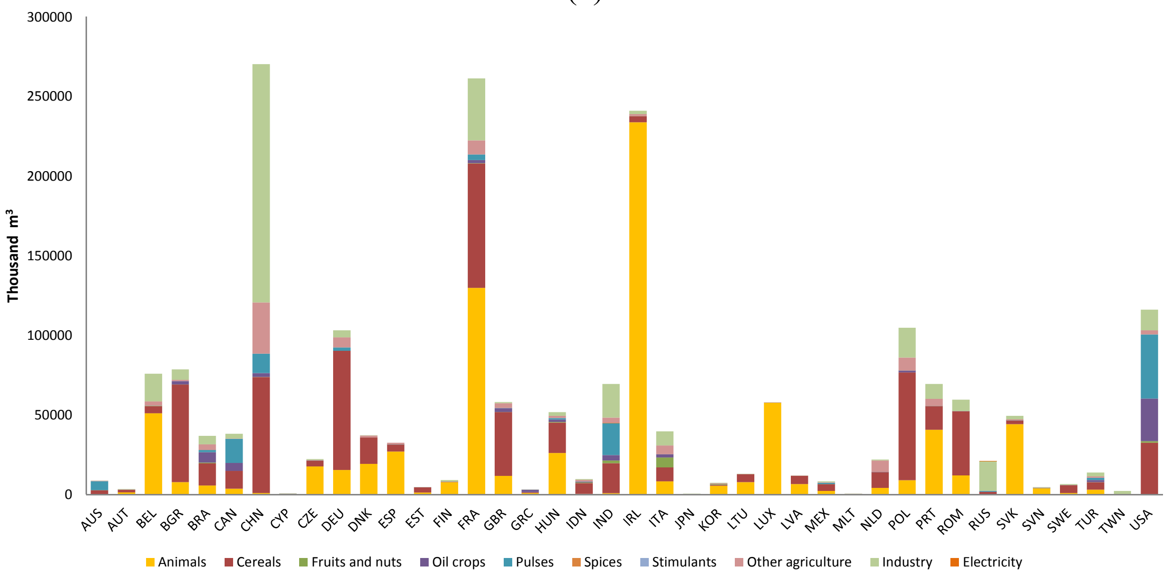
Finally, as for grey water (Figure 4), in 1995, it was imported as embodied in animals and cereals from France and also in cereals, oil crops and pulses. Growing these agricultural products involves important impacts on water resources, and Spain prevented water pollution by importing these products. In 2009, Spain still imported grey water from France and the share for the USA fell in Spanish food imports. Nonetheless, the most remarkable feature was the great increase of grey water imports from China embodied in industrial products, cereals, pulses or vegetables. Furthermore, in 2009, Spain increasingly imported grey water from Poland, Romania and Bulgaria embodied in cereals and from Ireland embodied in animals.

Thus, in the balance, the Spanish food sector was a net importer of water resources. That is, the volume of water obtained from abroad was higher than the water resources provided to the rest of the world. This is found for green, blue and grey water. Moreover, this pattern tended to consolidate, *i.e.*, the gap between virtual water imports and exports kept on widening between 1995 and 2009. This was particularly intense for green water and less profound in the case of blue water.

When looking at a particular sector, it is also of great importance to analyze the exchanges of water embodied with other domestic sectors (Table 3). This is essential in the Spanish food sector, since it shows remarkable backward and forward linkages with other Spanish industries. In fact, the Spanish food industry gets 16,762 million m^3 embodied in products from other domestic sectors. Around 84% of these inputs are used to produce food output that is domestically consumed, and the remaining 16% is exported. However, the Spanish food sector only provides 15.8 million m^3 to other Spanish industries. Looking at the backward linkages first, it seems quite clear that between 1995 and 2009, there was a reduction in the volume of water embodied in inputs purchased from other domestic sectors. Firstly, water was obtained as embodied in animals, cereals, dairy products, eggs, fruits, nuts, sugar crops and electricity, both in 1995 and 2009. Nevertheless, the volume of water obtained through these products tended to decrease during these years, with the exception of the backward linkages with the electricity sector that tended to strengthen.



(**a**)



(**b**)

Figure 4. Grey virtual water imports of the food sector by country and sector in 1995 (**a**) and 2009 (**b**), thousand m^3.

Besides, there was also a trend towards the strengthening of the forward linkages with other Spanish sectors that also increased the consumption of domestic blue water. The Spanish food sector has a strong dependency on the final demand of the hotel and restaurant sector, which stands out as the main final consumer of Spanish blue water and whose water demands increased from 1995 to 2009. In addition, Spain also obtained water embodied in inputs from other domestic sectors to export food products to countries, such as Belgium, France, Italy, Netherlands, China, Poland, among others.

Table 3. Water embodied in Spanish food sector purchases from domestic sectors, thousand m^3.

Product	1995			2009		
	Blue	**Green**	**Grey**	**Green**	**Blue**	**Grey**
Animals	14,166	71,989	10,596	11,992	59,260	9074
Cereals	1,613	5,866	1,583	1,339	4,732	1,315
Fruits and nuts	64	874	11	48	620	11
Milk and eggs	353	2368	404	296	1928	337
Oil crops	0	28	1	0	22	1
Pulses	16	230	9	11	152	7
Roots and tubers	78	88	52	64	73	44
Sugar crops	147	116	69	124	99	60
Vegetables	10	405	25	8	308	19
Food, Beverages and Tobacco	24	0	0	25	0	0
Pulp, Paper, Paper , Printing and Publishing	4	1	1	0	0	0
Chemicals and Chemical Products	4	1	1	4	1	1
Electricity, Gas and Water Supply	307	49	49	4	1	1

Given the former findings, it is possible to say that during the period 1995–2009, the Spanish food industry went through a process of commercial integration in international trade that resulted in growing pressures on domestic water resources. These pressures took place mostly through the intense, but also decreasing backward linkages with Spanish agriculture. In this line, it seems to be a kind of substitution effect, decreasing imports of water from other Spanish sectors (mainly agriculture), but increasing imports of agricultural goods from abroad. From an environmental perspective, this would mean a tendency towards reducing the pressure on domestic water resources by means of imports of intermediate products, but increasing environmental damage abroad. In the case of blue water, this substitution was so intense, that it involved a drop of embodied water consumption between 1995 and 2009. Besides, Spain exported goods that were chiefly used as intermediate inputs in the food sector of other countries, *i.e.*, it exerted damage on its natural resources to produce goods that were further processed in other countries, with these areas being the ones that obtained the higher share on the total value added. Moreover, water embodied in food output was also finally consumed by the Spanish hotel and restaurant sector.

As we can see in Table 2, embodied water consumption increased for green and grey water between 1995 and 2009; nonetheless, it fell in the case of blue water. This decline was a direct consequence of the intense drop experienced by virtual water imports from other Spanish sectors previously seen, despite virtual water imports from other countries growing. Therefore, we can say that there was a clear increase in the final consumption responsibility of the Spanish food sector for green and grey water. On the contrary, as for blue water, the final consumption responsibility falls during this period. Quite the opposite, the production responsibility of the Spanish food sector grew, that is domestic direct water consumption rose. Given these trends, in the following, we are applying structural decomposition analysis, trying to quantify the factors behind changes in the final consumption and production responsibilities of the Spanish food sector.

The increase in the embodied green water consumption happening between 1995 and 2009 was mainly due to the growth in the demand for water of the food sector in Spain, that is the scale effect (see

Table 4). This demand was mainly driven by water embodied in animals and cereals produced in Spain, as well as by water embodied in animals from ROW, France and Portugal, Cereals from China or ROW, Oil Crops from ROW, Brazil and the USA or stimulants from ROW. In this regard, it is important to highlight that the scale effect was higher if we compare the demand for water embodied in foreign goods (550%) to the Spanish demand for water embodied in domestic final goods (100%). Additionally, embodied green water consumption was also boosted by the backward technological effect. There seems to be a tendency towards the reduction of input purchases from countries that would involve a deceleration of water consumption, such as, for example, animals from Ireland and France, oil crops from the USA, cereals from France or stimulants from ROW and Russia. However during these years, imports of intermediate inputs from other countries that utilize more water-intense technologies increased. This is the case of the upsurge of animal imports from ROW, Slovak Republic, Romania and Lithuania or cereals imports from Romania, Poland or Bulgaria. Hence, these inputs coming from abroad and embodying large volumes of green water also made embodied green water consumption to rise (90%).

As shown in Table 4, the picture on grey water was quite similar to the former, but we can also find some peculiarities. The great boost of the demand for final domestic and imported goods also entailed an increase in the embodied grey water consumption. Domestic and foreign water intensity changes (mainly in the cereals and animals sectors from ROW, Spain and China), as well as changes in domestic technology grey water consumption declined.

Table 4. Decomposition analysis of water consumption.

Consumer Approach/Embodied Water Consumption							
Water type	**Water change (Thousand m^3)**	**Domestic intensity (%)**	**Imported intensity (%)**	**Domestic technology (%)**	**Backward technology (%)**	**Domestic demand (%)**	**Demand for imports (%)**
Blue	−1,568,777	209	107	−2	−22	−45	−146
Green	−3,946,015	446	375	23	−90	−100	−555
Grey	−679,231	331	182	17	−7	−74	−349
Producer Approach/Direct Water Consumption							
Water type	**Water Change (Thousand m^3)**	**Intensity (%)**		**Domestic technology (%)**	**Forward technology (%)**	**Domestic demand (%)**	**Foreign demand (%)**
Blue	8427	0		−10	4	50	56

As for blue water, embodied water consumption decreased during these years. In this case, the large upsurge of demand, *i.e.*, the scale effect, was totally made up by the negative contribution of water intensity and domestic technology changes. Again, it was the large demand for animals and cereals, both from Spanish and foreign agricultural sectors, that involved the largest pressure on global blue water resources. Regarding the technology effect, it is also possible to find foreign technological improvements that moderate water consumption, particularly in the case of oil crops in the USA or animals in Ireland and France. However, given the growing imports of blue water embodied in animals from ROW, in cereals from China, Romania and India or in electricity from Russia and China, the backward technological effect displays a slight, but positive sign. Finally, intensity changes also contributed to the deceleration of embodied blue water consumption (10%).

In the case of blue water direct consumption (Table 4), we found an increase of around 8427 thousand m^3. This increase was triggered by the scale effect. Both internal (50%) and foreign (56%) demand for final food products boosted blue water consumption. These increasing demands for goods produced in the Spanish food industry that embody large volumes of blue water were driven by the Spanish hotel and restaurant sector and also by other European food sectors, like the ones in France, Italy, Portugal, Germany and Great Britain. The construction, health and social work sectors in Spain also exerted some pressure on blue water. The forward technology effect also involved a larger consumption of blue water, although to a lesser extent (4%). This can be associated with the growing exports to the food sectors in ROW, France, Portugal, Germany, Italy and also the hotel and restaurant sectors in France. Finally, intensity changes in the Spanish food sector, but mostly domestic technological improvements, made direct blue water consumption increase and then level off.

Accordingly, the change in the water consumption of the Spanish food industry between 1995 and 2009 was mainly associated with the growth of domestic demand, as well as the increasing trade exchanges with other countries. On the one hand, the notable economic growth experienced in Spain during these years led to a generalized increase in households' income, also implying changes in lifestyles and consumption patterns. In this regard, Cazcarro *et al.* [40] showed that the consumption patterns of households, whose diets present a high meat content, are behind an important share of total water consumption in Spain. On the other hand, trade has alleviated, to some extent, the pressures on water resources through imports of agricultural inputs.

4. Conclusions

In this paper, the Spanish food industry has been analyzed from an environmentally multiregional input-output approach. This study offers insights into the importance of studying the impact of the food sector on water resources over global international chains, considering both direct and indirect water consumption. In fact, we show the strong pressures that the Spanish food industry has exerted on domestic and foreign water resources given the strengthening of the interrelations among sectors and countries happened between 1995 and 2009. Demand growth together with changes in consumption patterns and the growing commercial exchanges during these years have been key to explain the trend followed by water consumption.

The Spanish food sector has gone through a process of growing vertical integration in global and domestic supply chains that has involved increasing pressures on water ecosystems all over the world. This industry presents important backward linkages with the agriculture and electricity sectors in Spain and the rest of the world, meaning that it obtains water embodied in intermediate products that will be subsequently processed. Besides, there is a tendency towards the substitution of water embodied in domestic for imported agricultural inputs, entailing an externalization of the pressures on water resources. It happened for the three types/kinds of water considered, but was particularly intense in the case of blue water, involving a decline in embodied blue water consumption during these years. This was a direct consequence of the decreasing backward linkages with domestic agricultural sectors, mostly cereals and animals. Nevertheless, these products were increasingly imported from other countries, such as Ireland, Portugal, France, China and the rest of the world. This substitution prevented higher water consumption in Spain. However, water crystallized in the products of the food industry grew at the global level, since Ireland, ROW and Portugal produced cereals and particularly animals with higher green water than Spain. In this period, we also found growing forward linkages with the food industry sectors of other countries and with the hotel and restaurant sector in Spain.

The increase in green and grey embodied water consumption was mostly driven by the growing demand of food products. However, water intensity, together with changes in domestic technologies and also the backward technological effect for grey water, triggered the deceleration of water embodied. The contribution of the former effects and more concretely of the improvement of Spanish technology were so intense in the case of blue water, that it totally made up for the boost of the scale effect.

Although it is necessary to be aware of the methodological and conceptual uncertainties of the water footprint and virtual water concepts [41,42], the study of water embodied in domestic and international flows, providing a consumption-based perspective of the water consumption at the global level, represents an informative tool, which may be useful for policy makers at different decisional scales (local, national and supranational). In this line, Hoekstra and Mekkonen [12] show that the large volume of international virtual water flows and the associated water dependencies make it necessary to study water scarcity in a global context. However, as some studies argue [43,44], it is necessary to identify the flows coming from water-scarce areas before concrete drawing policy implications. Dalin *et al.* [45] indicate that it is possible to obtain global water savings from virtual water trade due to an increase in the proportion of water-efficient relationships, an increase in volumes of food traded through efficient trade relationships and an increase in the gap between the virtual content of products in the importing country and the exporting country. In this line, as Cazcarro *et al.* [46] suggest, using traceability indicators of water to inform about the water content of products could be a way to improve water management and reduce environmental impacts. Multiregional models can be therefore an interesting tool to track water demands from production to consumption through global supply chains, offering useful information on the economic demands and their associated environmental impacts.

Hence, this paper offers an empirical application of the way that the existing linkages on the global economies affect water resources. It is necessary therefore to develop comprehensive assessments of the use and consumption of water in the economies to understand which countries and sectors are the main contributors to water consumption trends. That way, it would be possible to study the relationship between global water scarcity and food security in a more general framework. Furthermore, it seems essential to promote the improvement of technologies, as well as the moderation and change of demand patterns, looking for more sustainable economies.

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Author Contributions

All the authors made substantial contributions to the conception and design, as well as to the analysis and interpretation of data

Conflicts of Interest

The authors declare that there is no conflict of interest.

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