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Water content in trade: a regional analysis for Morocco

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ABSTRACT

This paper aims at evaluating the virtual water content in trade in an intra-country perspective and discussing potential tradeoffs between the use of natural resources and value added creation. We develop a trade-based index that reveals the relative water use intensities associated with specific interregional and international trade flows. The index is calculated considering the measures of water and value added embedded in trade flows associated with each regional origin-destination pair using an interregional input-output matrix for Morocco together with information on sectorial water use. We add to the literature on virtual water by encompassing the subnational perspective in a country that shows a clear 'climate divide'. Furthermore, we contribute to the literature by proposing an index that may be applied to different economies to evaluate multidimensional tradeoffs associated with the pressure of specific economic flows to the use of natural resources relative to its economic relevance.

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1. Introduction

Considered as one of the most poorly endowed countries in water resources, Morocco has intimately linked its economic and social development to the control of its natural resources. The country has developed strategies and policies aiming at the best management and valorization of such resources. It has built, in the last decades, a large system of hydropower infrastructure consisting of approximately 139 large dams, with a storage capacity of more than 17 billion m^3, and several transfer systems that allow the physical transposition of water to the driest areas (Court of Audit, 2018).

These strategies have played a key role in food, water, and energy security for the population, particularly through improved access to drinking water and hydroelectric power, as well as protection against floods and droughts. Nevertheless, good governance of water resources requires continuing attention in Morocco, especially in the face of a significant increase in the demand for water and its multiple uses in the context of a growing population and an expanding economy (Global Nexus, 2017). Moreover, adding to the long-term changes to recent dry conditions in Morocco, global climate change is projected to increase

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the frequency, length and severity of drought episodes in the country, directly and indirectly compromising the living standards of the population (Esper et al., 2007; Imani et al., 2014; Masih et al., 2014; Roson & Sartori, 2015).

In addition to physical relocation processes, interregional transfers of water resources also take place virtually through trade flows (Allan, 1993). For a given set of available technologies, differences in relative abundance of water in a region, together with a comparison of the full cost structure among regional trade partners, may generate regional comparative advantage in water-intensive sectors, such as agriculture (Duchin & López-Morales, 2012; Wichelns, 2004).[1] Such differences are revealed in the structure of interregional trade, in which virtual water flows are associated with the resources embedded in the production chain of the traded goods.

Research on water accounting, mainly related to international trade flows, has boosted in the last few years with the development of worldwide input–output systems and the stronger concern with resources availability in the context of global climate change (Cai et al., 2019; Daniels et al., 2011; Dietzenbacher & Velázquez, 2007; Feng et al., 2011; Han et al., 2018; Hoekstra & Chapagain, 2008; Hoekstra & Hung, 2002; Lenzen et al., 2013a; Tamea et al., 2016; Zhang & Anadon, 2014). Accountability of the pressure on the use of the world's natural resources has reached the political debate, as attempts to characterize countries according to their historical, current and expected role played in this process has reopened political fissures (Victor et al., 2014). Similarly to nations, regions within countries can also be characterized by their pressure on the demand for natural resources. As shown by Hoekstra and Chapagain (2008), local water depletion is often closely tied to the structure of the global economy. For regions within a country, the national economy adds another layer to the relevant structural hierarchy to understand resources uses (Liu et al., 2019; Visentin, 2017; Visentin & Guilhoto, 2019; Zhang et al., 2016).

Furthermore, different studies have analyzed virtual water flows in different regional contexts (Aldaya et al., 2010; Cai et al., 2019; Duarte et al., 2014; Duarte et al., 2019; Fracasso, 2014; Han et al., 2018; Liu et al., 2019; Wang et al., 2019; Zhang et al., 2011; Zhang & Anadon, 2014; Zhang et al., 2016; Zhang et al., 2017); nonetheless few of them had their focus in Morocco: while the regional dimension has usually been considered only in physical terms (Imani et al., 2014; Masih et al., 2014), those that addressed virtual water aspects have focused mainly on national/sectoral outcomes. Schyns and Hoekstra (2014) carried out a detailed Water Footprint Assessment for Morocco. Using a bottom-up water footprint accounting approach, the authors were able to map the water footprint of different activities at river basin and monthly scale, distinguishing between surface- and groundwater. Boudhar et al. (2017) developed their study relying on a top-down approach based on input–output analysis. The authors used a national input–output model of water use to analyze the relationships between economic sectors and water resources use in Morocco (i.e. direct water use) as well as the intersectoral water relationships (i.e. indirect water use). The results provided insights on a categorization of sectors that exhibits higher direct water use and those with higher indirect water use.[2]

[1] If two regions engage in trade, each will have incentives to increase production of goods in which it has the lower relative marginal cost prior to trade than the other (Dixit & Norman, 1980). *Ceteris paribus*, water rich areas will tend to export water-intensive goods, for which the will likely have a relative cost advantage.

[2] From a methodological standpoint, the differences between bottom-up and top-down approaches are due to intersectoral effects (Feng et al., 2011). While bottom-up approaches do not fully trace intersectoral linkages, top-down

In this paper, we have opted to follow a top-down approach, adding to previous work the integrated water-economic analysis of supply chains in an explicit regional (sub-national) setting.

In this context, this paper aims at evaluating the virtual water content in trade in an intra-country perspective, and discussing potential tradeoffs between the use of natural resources and value added creation. Is a particular regional export flow relatively more intensive in domestic traded water or in domestic traded value added? Does it put more pressure on the use of natural resources in relation to its capacity of creating regional value added?

To address these issues, we develop a trade-based index that reveals the relative water use intensities associated with specific interregional and international trade flows. The Trade-Based Index of Water Intensity (TWI) is calculated considering the measures of water and value added embedded in trade flows associated with each regional origin-destination pair through the use of an interregional input–output matrix for Morocco (IOM-MOR) together with information on water use by sector. The Moroccan case is a particularly interesting example in the Middle East and North Africa (MENA) region, presenting increasing demand for water with distinct spatial water regimes across its territory.

The concept of virtual water in this paper is defined within the input–output framework, which determines the virtual water content via coefficients of water quantity per monetary unit of a given product (Dietzenbacher & Velázquez, 2007). The parsimonious approach proposed in Los et al. (2016), based on 'hypothetical extraction', serves as the methodological anchor for the measurement of the water and value added contents embedded in trade flows, the bases for the index.

We add to the existing literature on virtual water flows by encompassing the subnational perspective in the case study of a country that shows a clear cut 'climate divide' – while a great part of the southern territory of Morocco is located in the Sahara Desert, with serious water constraints, the northern part is relatively more privileged with access to this natural resource. Thus, using a top-down approach, we add to previous work the integrated water-economic analysis of supply chains in an explicit regional (sub-national) setting. Furthermore, we contribute to the literature by proposing an index that may be applied to different economies to evaluate multidimensional trade-offs associated with the pressure of specific economic flows to the use of natural resources relative to its economic relevance.[3]

In what follows, Section 2 presents different dimensions of regional disparities in Morocco, considering the geography of water and the spatial economic structure of the country. Section 3 describes the methodology to be used in Section 4 to measure the water and value added in interregional trade in Morocco, illustrating the use of the proposed index (TWI) to analyze the tradeoff that emerges when one compares the embedded water in specific regional export flows to the value added they create. Section 5 concludes.

approaches, based on input–output techniques, are able to calculate the water footprint by tracing the whole supply chains.

[3] Heterogeneous climate regimes are not unique to Morocco. Many countries present internal climatic differences and very uneven distributions of water resources. Similar analyses to the one in this paper could be undertaken for such countries for which there are also interregional input–output databases available (e.g. Brazil, Chile, China, Colombia, Mexico, USA).

2. Dimensions of regional disparities in Morocco

2.1. The geography of water resources

Located in Northern Africa, bordering the Mediterranean in the north and the Atlantic Ocean in the west, Morocco is characterized by diversified reliefs ranging from the mountains in the Rif and the Atlas, passing through plains and central plateaus, and ending in the south in a vast desert area. The heterogeneity observed at the level of the reliefs in Morocco has predestined the country to have a temperate climate marked by contrasts in space and time, and associated with increasing scarcity of water resources.

These natural physical constraints have forced the country to create the capability of storing water during periods of abundant rainfall for use during periods of scarcity, and to transfer water from the surplus basins of the northwest to the deficit basins of the center and the south. This mechanism allows the government to design an integral development plan for all regions of the country taking into consideration different dimensions of regional disparities. Moreover, these natural complexities are exacerbated by excessive evaporation, extensive evapotranspiration and also frequent periods of droughts that result from the impacts of climate variability, which tend to become even more intense in the context of global climate change.

Marked by evident space-temporal variability, rainfall in Morocco is gradually becoming scarce, going eastwards in the Mediterranean zone and towards the south in the Atlantic zone. In fact, the average annual national rainfall varies from 500–1000 mm in the northwest part of the country to less than 100 mm in the arid zones: (i) greater than 800 mm in the most rich area in terms of water resources located in the northwest; (ii) from 600 to 800 mm in the north and the Atlas zone; (iii) from 400 to 600 mm in the Sebou, Bouregreg and Oum Rbia areas; (iv) from 200 to 400 mm in the Tensift, Souss Massa and the Oriental areas; and (v) less than 200 mm in the southern Atlas areas and the Sahara.

According to the inventory of water resources in Morocco, it is estimated that 22 billion cubic meters of water can be withdrawn, of which 18 billion are surface water. In addition, close to 60% of the country's surface water resources are located in the Atlantic and central basins, which account for less than one fifth of the territory. In contrast, the Saharan basins, which cover half of the country, account for less than 6% of total surface water availability.

As far as groundwater is concerned, 4 billion m^3 per year are withdrawn from aquifers. Throughout the Moroccan territory, more than 78 groundwater wells are identified. These water resources constitute an important part of the national water heritage and sometimes represent the only water resources of the desert regions. Although very rare, these resources participate actively to the economic development of the Saharan areas.

2.2. The geography of economic activity

The use of a regionalization based on river basins is fundamental for studies dealing with impact assessment of the use of water resources on their availability to extract measures of sustainability (Visentin, 2017). Nonetheless, regionalization issues arise when one attempts to integrate other quantifiable dimensions for which data are collected under different geographical definitions. This is the case for regional economic statistics in Morocco, which are available for administrative divisions whose limits differ from those of the river basins.

Table 1. Basic Socioeconomic Indicators for Morocco, 2013.

	Population (1,000)		GRP/GDP (in million DHS)		Per Capita GRP/GDP (in DHS)	
Region	2013	%	2013	%	2013	Share of National
Tanger-Tetouan-Al Hoceima	3,344	10.15	65,373	7.95	19.551	0.78
Oriental	2,219	6.73	52,031	6.33	23.449	0.94
Fès-Meknès	4,257	12.92	81,145	9.87	19.061	0.76
Rabat-Salé-Kénitra	4,674	14.19	123,331	15.01	26.385	1.06
Béni Mellal-Khénifra	2,505	7.60	57,814	7.03	23.082	0.93
Grand Casablanca-Settat	6,425	19.50	241,976	29.44	37.662	1.51
Marrakech-Safi	4,289	13.02	91,593	11.14	21.355	0.86
Drâa-Tafilalet	1,489	4.52	24,017	2.92	16.127	0.65
Souss-Massa	2,684	8.15	55,228	6.72	20.576	0.82
Guelmim-Oued Noun	455	1.38	10,643	1.29	23.398	0.94
Laayoune-Sakia El Hamra	406	1.23	14,267	1.74	35.141	1.41
Dakhla-Oued Eddahab	203	0.62	4,438	0.54	21.863	0.88
MOROCCO	32,950	100.00	821,856	100.00	24.943	1.00

Source: High Commission for Planning and IOM-MOR.
Note: GRP is the Gross Regional Product.

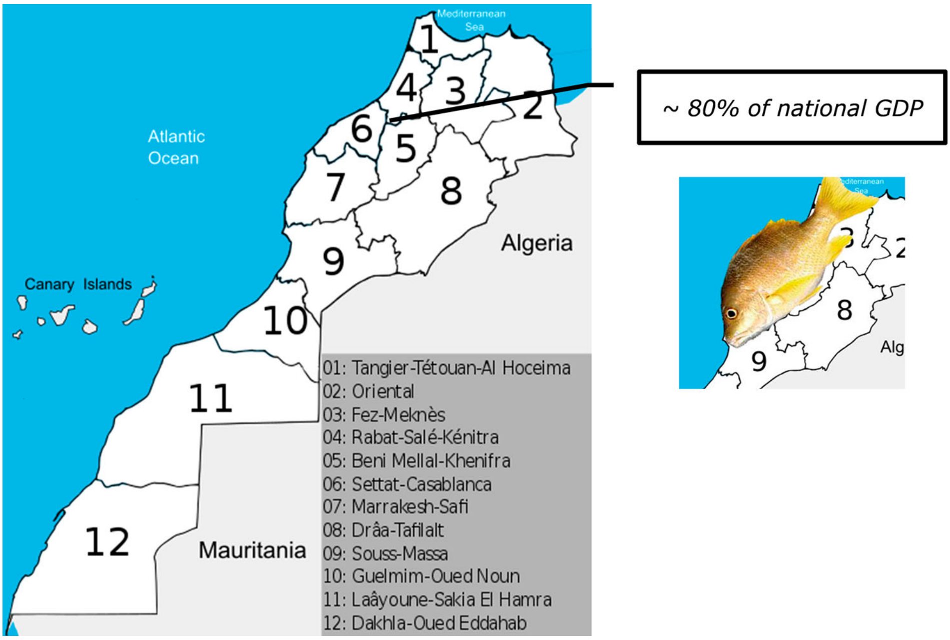
Given the twelve-region setting of the IOM-MOR, and the nine-basin setting of the Moroccan watershed system, a one-to-one mapping is not available. Thus, a different regional perspective, based on administrative regions, will permeate the forthcoming analysis, to be also used throughout the rest of the paper.

Information on the regional distribution of population and GDP (Table 1) shows Grand Casablanca-Settat as the prime region of the country. It concentrates approximately 20% of the population and 30% of national GDP. Higher productivity levels are perceived mainly in the two largest urban agglomerations of the country, which present higher GDP shares than population shares. In a broader territorial context, the presence of other relevant industrial areas outside Casablanca reveals the economic core of the Moroccan economy comprising six of the twelve regions, namely, Tanger-Tetouan-Al Hoceima (R1), Fès-Meknès (R3), Rabat-Salé-Kénitra (R4), Béni Mellal-Khénifra (R5), Grand Casablanca-Settat (R6) and Marrakech-Safi (R7), which, together, are responsible for over 80% of the GDP. Given the fish-shaped-like cartographical representation of the territorial limits of this cluster, this set of regions is referred to as 'the fish' (Figure 1).

The input-output system for Morocco (IOM-MOR) is calibrated for 2013 and considers 12 regions and 20 sectors (Haddad et al., 2017). In productive terms, five relatively more integrated regions, all of them part of the 'fish', concentrated most of the flows of goods and services: Casablanca, Rabat, Marrakech, Fès-Meknès, and Tanger. These regions were responsible for more than 75% of the total output value of the Moroccan economy in 2013. For the remaining regions, there is practically little integration among them, with the production linkages taking place mainly inside each one of them, with some trade with Casablanca.

In regional output terms, Casablanca dominates the national production, with a share of 35.7% in total output, followed by Rabat (13.0%), Marrakech (9.9%), Fès-Meknès (9.2%) and Tanger (8.8%). The regional output shares by sectors in Morocco reveal some evidence of spatial concentration of specific activities: agriculture in Fès-Meknès, Marrakech, Rabat, Casablanca, and Béni (69.7% of total output); fishing in Souss-Massa, Dakhla-Oued Eddahab, Guelmin-Oued Noun and Laayoune-Sakia Le Hamra (79.0%); mining in Béni

Figure 1. Regional Setting in Morocco: Administrative Regions and the 'Fish'.



and Marrakech (78.0%), manufacturing in Casablanca, where at least 50% of the output is generated for each of the sectors. Some regions play important roles in the production of specific manufacturing sectors, such as food industry in Souss-Massa (12.6%) and Fès-Meknès (9.9%); textile and leather in Tangier (21.3%) and Fès-Meknès (11.3%); and mechanical, metal and electrical products in Tangier (26.4%). Services, in general, are concentrated in Rabat and Casablanca. However, Marrakech and Souss-Massa concentrate the major part of tourism services (36.8% and 26.4%, respectively).

Finally, the sectoral regional output reveal the important role of some activities in relatively specialized regions: the dominant role of agriculture in Drâa-Tafilalet (27.5% of total regional output), Béni (25.6%) and Fès-Meknès (21.7%); fishing in Dahla-Oued Eddahab (38.6%); mining in Béni (21.%); food industry in Souss-Massa (21.1%); and the relevance of the public administration in the more remote regions of the south: Guelmin-Oued Noun (28.0%), Laayoune-Sakia Le Hamra (27.7%) and Dakhla-Oued Eddahab (20.7%).

3. Methodology

The analysis in the previous section has revealed distinct spatial regimes associated with both the geography of water resources and the geography of economic activity in Morocco. On one hand, the climate divide, heavily influenced by the physical barrier established by the Atlas mountain range, affects regional water availability, potentially creating regionally differentiated comparative advantage on water-resource-intensive sectors. On the other hand, the regional distribution of economic activity and population creates a complex structure of supply and demand in space that helps shaping the geography of trade flows and domestic value chains (Meng et al., 2017).

In a context in which interregional physical transfers of water do not suffice to respond to specific regional needs, what role do virtual water trade flows play? Coming up with appropriate methods to measure interregional trade in water may be deem important for water management in a country like Morocco, characterized by a very heterogeneous availability across its regions. Thus, in this Section, we describe the method to be applied in the calculation of our Trade-Based Index of Water Intensity (TWI). It takes into consideration important elements of an integrated interregional system and the demand of natural resources, namely information on the adopted technology by different sectors in the form of input–output linkages, the specific regional economic structures, the structure of interregional and international trade flows, and information on water use by sectors.

3.1. Background

Los et al. (2016) have proposed a decomposition of gross exports based on the 'hypothetical extraction' (HE) methodology, which allows quantifying how much of domestic value added is included in a country's exports. The measurement proposed by the authors is based on multi-country input–output tables.

In the case of national interregional input–output tables, with n domestic regions, the ideal framework to evaluate the domestic value added in exports would be to have a multi-country input–output table, in which the national system would be inserted into the multi-country model. However, such a system would demand a large amount of information, such as trade flows from each sector in each domestic region to each sector in each other country in the Rest of the World (RoW), and vice versa. Thus, given that there is no subnational information for Morocco in multi-country input–output databases, we follow an alternative approach in which the RoW is considered as an exogenous region, i.e. as a column vector in the final demand of a national interregional system.

Thus, following Los et al. (2016), we calculate the domestic value added in exports (DVA) based on a national interregional input–output system with exports to the RoW exogenously specified. Furthermore, by the same logic, we adapt the methodology to measure domestic traded water in exports (DTW). Finally, using both measures, we calculate the Trade-Based Index of Water Intensity (TWI).

3.2. Measurement of domestic value added in exports

The input–output model can be expressed by

$$\mathbf{x} = \mathbf{Ax} + \mathbf{f} \tag{1}$$

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

where $\mathbf{x}$ and $\mathbf{f}$ are the vectors of gross output and final demand; $\mathbf{A}$ is a matrix with the input coefficients (a_{ij}); $\mathbf{I}$ is the identity matrix; and $\mathbf{L}$ is the Leontief inverse.

Considering a national interregional input–output model with n different regions and the RoW as a column vector in the final demand, (1) and (2) can be represented as

$$\begin{bmatrix} \mathbf{x}^1 \\ \vdots \\ \mathbf{x}^\mathbf{n} \end{bmatrix} = \begin{bmatrix} \mathbf{A}^{11} & \cdots & \mathbf{A}^{1\text{n}} \\ \vdots & \ddots & \vdots \\ \mathbf{A}^{\text{n}1} & \cdots & \mathbf{A}^{\text{nn}} \end{bmatrix} \begin{bmatrix} \mathbf{x}^1 \\ \vdots \\ \mathbf{x}^\text{n} \end{bmatrix} + \begin{bmatrix} \mathbf{f}^{11} & \cdots & \mathbf{f}^{1\text{n}} & \mathbf{f}^{1\mathbf{row}} \\ \vdots & \ddots & \vdots & \vdots \\ \mathbf{f}^{\text{n}1} & \cdots & \mathbf{f}^{\text{nn}} & \mathbf{f}^{\mathbf{nrow}} \end{bmatrix} \mathbf{i} \tag{3}$$

$$\begin{aligned} \begin{bmatrix} \mathbf{x}^1 \\ \vdots \\ \mathbf{x}^\text{n} \end{bmatrix} &= \left\{ \begin{bmatrix} \mathbf{I} & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \mathbf{I} \end{bmatrix} - \begin{bmatrix} \mathbf{A}^{11} & \cdots & \mathbf{A}^{1\text{n}} \\ \vdots & \ddots & \vdots \\ \mathbf{A}^{\text{n}1} & \cdots & \mathbf{A}^{\text{nn}} \end{bmatrix} \right\}^{-1} \begin{bmatrix} \mathbf{f}^{11} & \cdots & \mathbf{f}^{1\text{n}} & \mathbf{f}^{1\mathbf{row}} \\ \vdots & \ddots & \vdots & \vdots \\ \mathbf{f}^{\text{n}1} & \cdots & \mathbf{f}^{\text{nn}} & \mathbf{f}^{\mathbf{nrow}} \end{bmatrix} \\ \mathbf{i} &= \begin{bmatrix} \mathbf{L}^{11} & \cdots & \mathbf{L}^{1\text{n}} \\ \vdots & \ddots & \vdots \\ \mathbf{L}^{\text{n}1} & \cdots & \mathbf{L}^{\text{nn}} \end{bmatrix} \begin{bmatrix} \mathbf{f}^{11} & \cdots & \mathbf{f}^{1\text{n}} & \mathbf{f}^{1\mathbf{row}} \\ \vdots & \ddots & \vdots & \vdots \\ \mathbf{f}^{\text{n}1} & \cdots & \mathbf{f}^{\text{nn}} & \mathbf{f}^{\mathbf{nrow}} \end{bmatrix} \mathbf{i} \end{aligned} \tag{4}$$

where $\mathbf{i}$ is a column vector with all elements equal unity which sums all elements in each of the $n+1$ rows of the matrix $\mathbf{f}$.

Following Los et al. (2016), the value added in region 1 (GDP_1) can be expressed as

$$GDP_1 = \mathbf{v}_1(\mathbf{I} - \mathbf{A})^{-1}\mathbf{fi} \tag{5}$$

where $\mathbf{v}_1$ is a row vector with ratios of value added to gross output in industries in region 1 as first elements ($\tilde{\mathbf{v}}_1$) and zeros elsewhere ($\mathbf{v}_1 = \begin{bmatrix} \tilde{\mathbf{v}}_1 & 0 \end{bmatrix}$); and $\mathbf{i}$ is a column vector which all elements are unity.

In order to attribute the amount of domestic value added in exports from region 1 to region n, as proposed by Los et al. (2016), we consider a hypothetical world where region 1 does not export anything to region n. In this case, the new GDP or hypothetical GDP can be represented by

$$GDP^*_{1,n} = \mathbf{v}_1(\mathbf{I} - \mathbf{A}^*_{1,n})^{-1}\mathbf{f}^*_{1,n}\mathbf{i} \tag{6}$$

where $\mathbf{A}^*_{1,n}$ and $\mathbf{f}^*_{1,n}$ are the hypothetical matrix of input coefficients and final demand, respectively, expressed as

$$A^*_{1,n} = \begin{bmatrix} A^{11} & \cdots & 0 \\ \vdots & \ddots & \vdots \\ A^{n1} & \cdots & A^{nn} \end{bmatrix} \tag{7}$$

$$\mathbf{f}^*_{1,n} = \begin{bmatrix} \mathbf{f}^{11} & \cdots & 0 & \mathbf{f}^{1\mathbf{row}} \\ \vdots & \ddots & \vdots & \vdots \\ \mathbf{f}^{\text{n}1} & \cdots & f^{nn} & f^{nrow} \end{bmatrix} \tag{8}$$

In addition, in order to attribute the amount of domestic value added in exports from region 1 to the RoW, we consider a hypothetical world where region 1 does not export to the RoW. In this case, the hypothetical GDP can be represented as

$$GDP^{*}_{1,row} = \mathbf{v}_1(\mathbf{I} - \mathbf{A})^{-1}\mathbf{f}^{*}_{1,row}\mathbf{i} \tag{9}$$

where $\mathbf{A}$ is the original matrix with the input coefficients as in (5); and $\mathbf{f}^{*}_{1,row}$ is the hypothetical matrix of final demand, expressed as

$$\mathbf{f}^{*}_{1,row} = \begin{bmatrix} \mathbf{f}^{11} & \cdots & \mathbf{f}^{1n} & 0 \\ \vdots & \ddots & \vdots & \vdots \\ \mathbf{f}^{n1} & \cdots & f^{nn} & f^{nrow} \end{bmatrix} \tag{10}$$

From (5) and (6), we can define the domestic value added in exports (DVA) from region 1 to region n as follows:

$$DVA_{1,n} = GDP_1 - GDP^{*}_{1,n} \tag{11}$$

and, from (5) and (9), we can define DVA in exports from region 1 to the RoW as

$$DVA_{1,row} = GDP_1 - GDP^{*}_{1,row} \tag{12}$$

Similarly, we can attribute the amount of domestic value added in exports from region 1 to all regions (2, 3, ... , n), and from each region to the n-regions (1, 2, ... , n), excluding itself. We can also attribute the DVA from each region to the RoW. In this sense, in an interregional system with n regions and the RoW exogenous, we have n DVA in exports for each region.

3.3. Measurement of domestic traded water in exports

Following the logic of the GDP, we can determine the total traded water (TTW) in region 1 as

$$TTW_1 = \mathbf{w}_1(\mathbf{I} - \mathbf{A})^{-1}\mathbf{fi} \tag{13}$$

where $\mathbf{w}_1$ is a row vector with water use in industries in region 1 as first elements ($\tilde{\mathbf{w}}_1$) and zeros elsewhere ($\mathbf{w}_1 = [\tilde{\mathbf{w}}_1 \quad 0]$); and $\mathbf{i}$ is a column vector which all elements are unity.

In order to attribute the amount of water in exports from region 1 to region n, we consider, similarly to (6), a hypothetical world where region 1 does not export anything to region n, which allows us to represent the hypothetical total traded water by

$$TTW^{*}_{1,n} = \mathbf{w}_1(\mathbf{I} - \mathbf{A}^{*}_{1,n})^{-1}\mathbf{f}^{*}_{1,n}\mathbf{i} \tag{14}$$

where $\mathbf{A}^{*}_{1,n}$ and $\mathbf{f}^{*}_{1,n}$ are expressed as (7) and (8), respectively.

And to attribute the amount of water in exports from region 1 to the RoW, we consider, similarly to (9), a hypothetical world where region 1 does not export anything to the RoW, represented by

$$TTW^{*}_{1,row} = \mathbf{w}_1(\mathbf{I} - \mathbf{A})^{-1}\mathbf{f}^{*}_{1,row}\mathbf{i} \tag{15}$$

where $\mathbf{A}$ is a matrix with the input coefficients as in (5); and $\mathbf{f}^{*}_{1,row}$ is expressed as (10).

From (13) and (14), we can define the domestic total traded water in exports (DTW) from region 1 to region n as

$$DTW_{1,n} = TTW_1 - TTW^*_{1,n} \quad (16)$$

and, from (13) and (15), we can define the DTW in exports from region 1 to the RoW as

$$DTW_{1,row} = TTW_1 - TTW^*_{1,row} \quad (17)$$

In a similar fashion, we can attribute the amount of domestic total traded water in exports from region 1 to all regions (2, 3, . . . , n) and from each region to the n-regions (1, 2, . . . , n), excluding itself, and from each region to the RoW. In the same sense than DVA, we have also n DTW for each region.

3.4. Trade-based index of water intensity

The trade-based index of water intensity (TWI) is based on the information on domestic value added in exports (DVA) and domestic total traded water in exports (DTW). The index calculation considers three steps. First, we calculate the relative importance of each domestic value added in export (I^{DVA}) inside the whole economy by computing the ratio of each DVA to the sum of all of them, expressed as

$$I^{DVA}_{n,k} = \frac{DVA_{n,k}}{\left[\sum_{i=1}^{n}\sum_{j=1}^{k} DVA_{n,k} + \sum_{i=1}^{n} DVA_{n,row}\right]}, i = 1, 2, \ldots, n; j = 1, 2, \ldots, k; \forall k \neq n \quad (18)$$

$$I^{DVA}_{n,row} = \frac{DVA_{n,row}}{\left[\sum_{i=1}^{n}\sum_{j=1}^{k} DVA_{n,k} + \sum_{i=1}^{n} DVA_{n,row}\right]}, i = 1, 2, \ldots, n; j = 1, 2, \ldots, k; \forall k \neq n \quad (19)$$

where n and k are the number of regions.

Second, by the same logic, we can calculate the relative importance of domestic total traded water in exports (I^{DTW}) inside the whole economy by computing the ratio of each DTW to the sum of all of them, expressed as

$$I^{DTW}_{n,k} = \frac{DTW_{n,k}}{\left[\sum_{i=1}^{n}\sum_{j=1}^{k} DTW_{n,k} + \sum_{i=1}^{n} DTW_{n,row}\right]}, \quad i = 1, 2, \ldots, n; j = 1, 2, \ldots, k; \forall k \neq n \quad (20)$$

$$I^{DTW}_{n,row} = \frac{DTW_{n,row}}{\left[\sum_{i=1}^{n}\sum_{j=1}^{k} DTW_{n,k} + \sum_{i=1}^{n} DTW_{n,row}\right]}, \quad i = 1, 2, \ldots, n; j = 1, 2, \ldots, k; \forall k \neq n \quad (21)$$

where n and k are the number of regions.

Finally, in the third step, taking in account the relative importance of each flow in terms of domestic value added in export (I^{DVA}) and of domestic total traded water in exports (I^{DTW}), we calculate the Trade-Based Index of Water Intensity (TWI) as follows

$$TWI_{n,k} = \frac{I^{DTW}_{n,k}}{I^{DVA}_{n,k}},\ i = 1, 2, \ldots, n;\ j = 1, 2, \ldots, k;\ \forall k \neq n \tag{22}$$

$$TWI_{n,row} = \frac{I^{DTW}_{n,row}}{I^{DVA}_{n,row}},\ i = 1, 2, \ldots, n;\ j = 1, 2, \ldots, k;\ \forall k \neq n \tag{23}$$

As before, we have n TWI for each region which can be interpreted as follows:

(i) if **greater** than 1, in that particular trade flow the region is more intensive in domestic total traded water in exports than in domestic value added in exports; and
(ii) if **lower** than 1, the opposite.

In other words, the TWI allows us observing, for each trade flow in Morocco, whether it creates, in relative terms, more domestic value added or put more pressure on the use of natural resources (i.e. water). Thus, the TWI may be used as a background for the discussion of potential tradeoffs between the use of local natural resources and regional economic performance.

4. Analysis

4.1. Data

The method described in Section 3 relies on the use of an interregional input–output system linked to a water accounting system. The IIOM-MOR was developed as part of a technical cooperation initiative involving researchers from the Regional and Urban Economics Lab at the University of São Paulo (NEREUS), in Brazil, and the OCP Policy Center (now Policy Center for the New South) and the Department of Economic Studies and Financial Forecast (DESFF), under the Ministry of Economy and Finance, both in Morocco (Haddad et al., 2017). A fully specified interregional input–output database was estimated for 2013, considering 20 sectors in 12 Moroccan regions (IOM-MOR). In terms of water accounting system, we use total water sectoral use coefficients from Eora database (Lenzen et al., 2012, 2013b).[4] Despite the fact that water use within a given activity differs across regions in Morocco (Schyns & Hoekstra, 2014), data availability precludes the use of regionally differentiated sectoral use coefficients in this study.[5]

In Eora, total water use (in m^3) is available for 26 Moroccan sectors[6], and the information includes different components, namely, (i) water footprint by crop demand; (ii)

[4] Eora is a multi-region input–output table (MRIO) database that provides a time series of high resolution IO tables with matching environmental and social satellite accounts for 190 countries. For more details, see Lenzen et al. (2012; 2013b).

[5] The lack of sectoral use coefficients for each region in Morocco is a limitation. It is implicitly assumed that the volume of water used is calculated under the same sectoral water technology. Thus, our results are an approximation to the ideal situation, which would have considered sector- and region-specific water coefficients, if available.

[6] The version of the model used in this paper is Eora26 MRIO, which aggregates all countries to a common 26-sector classification and converts the supply-use tables from the full Eora MRIO to symmetric product-by-product IO tables using the Industry Technology Assumption. This version is compatible with the procedures used to build the IOM-MOR and

Table 2. Coefficients of Water Use by Sector: Morocco, 2013.

Sectors		Water use (m^3/GO in 1,000,000 DHS)				
		Crop Water	Blue Water	Green Water	Grey Water	Total
A00	Agriculture, forestry, hunting, related services	189,116.14	12,113.38	281.99	27.90	201,539.39
B05	Fishing, aquaculture	0.00	5,612.29	127.25	0.00	5,739.54
C00	Mining industry	0.00	0.00	8.18	31.09	39.27
D01	Food industry and tobacco	31,942.30	22,984.21	535.05	52.94	55,514.49
D02	Textile and leather industry	163.43	0.00	21.65	82.28	267.37
D03	Chemical and para-chemical industry	0.00	0.00	28.05	106.58	134.63
D04	Mechanical, metallurgical and electrical industry	0.00	0.00	45.32	172.20	217.51
D05	Other manufacturing, excluding petroleum refining	0.00	11,165.40	292.73	150.39	11,608.52
D06	Oil refining and other energy products	0.00	0.00	28.05	106.58	134.63
E00	Electricity and water	0.00	0.00	17.55	66.69	84.24
F45	Construction	0.00	0.00	0.00	0.00	0.00
G00	Trade	0.00	0.00	0.00	0.00	0.00
H55	Hotels and restaurants	0.00	0.00	0.00	0.00	0.00
I01	Transport	0.00	0.00	0.00	0.00	0.00
I02	Post and telecommunications	0.00	0.00	0.00	0.00	0.00
J00	Financial activities and insurance	0.00	0.00	10.53	40.00	50.53
K00	Real estate, renting and services to enterprises	0.00	0.00	10.53	40.00	50.53
L75	General public administration and social security	0.00	0.00	0.00	0.00	0.00
MNO	Education, health and social action	0.00	0.00	0.00	0.00	0.00
OP0	Other non-financial services	0.00	0.00	0.00	0.00	0.00

Source: Eora and IOM-MOR.

water footprint of grazing (green water); (iii) water footprint of animal supply (blue); and (iv) water footprint of industrial production and water footprint of domestic water supply (grey).[7] The consolidated information is presented in Table 2, in which the adjusted coefficients are presented in m^3 per million DHS. The top sector in terms of direct water use is Agriculture, forestry, hunting, related activities (A00), whose total water use is mainly concentrated in the crop water use component. Food industry and tobacco (D01) is also a heavy user, with important shares of crop water and blue water use. Other manufacturing, excluding petroleum refining (D05) is also an important user, dominated by the blue water use component.

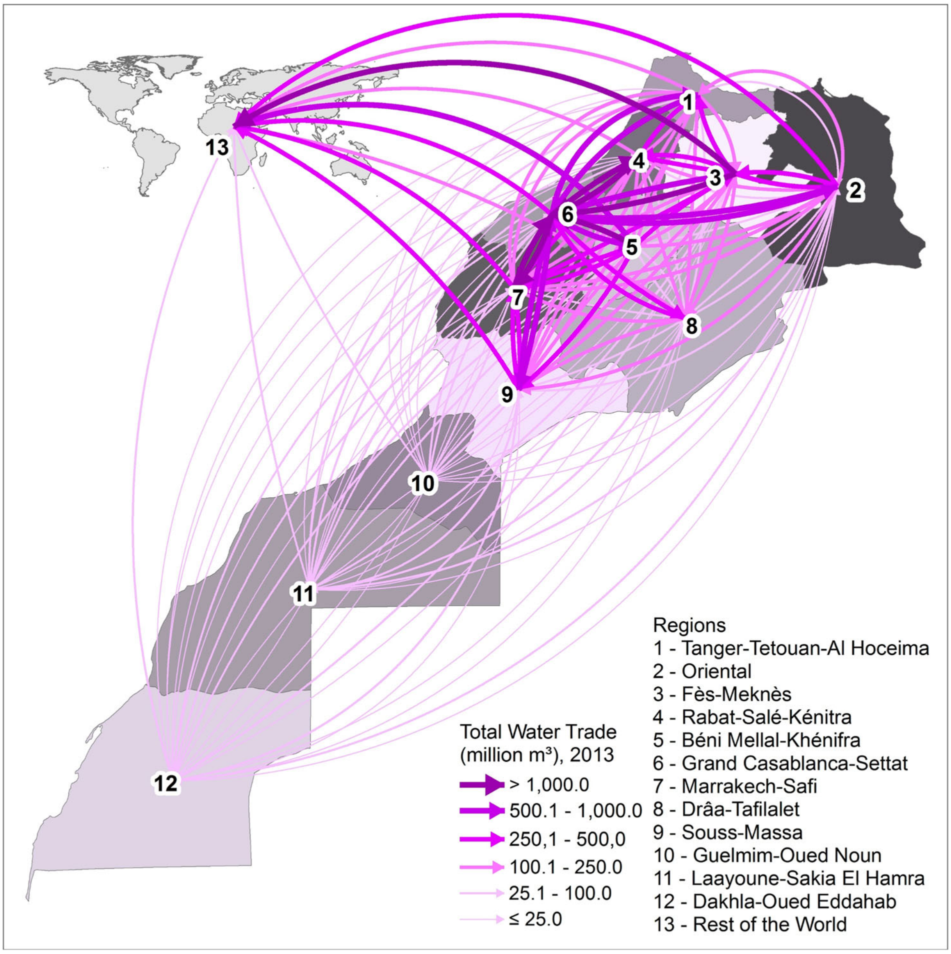
4.2. Results

We have first computed the values of DTW, with the domestic total traded water in interregional and international exports originating in each of the twelve Moroccan regions. We

a simple mapping was used to consolidate Moroccan data from the 26 sectors in Eora26 MRIO to the 20 sectors in IOM-MOR.

[7] The definition of water use follows the Eora database which differs from those categories used in other studies. For more details, see Lenzen et al. (2013a).

Figure 2. Total Traded Water in Exports (DTW).



have generated the results based on Equations 16 and 17 by using such information to construct the row vectors of sectoral water use in region.

We can map the results obtained from DTW[8] to visualize the geography of domestic total traded water in Morocco. Figure 2 depicts the 'shipments' of virtual water from each origin to all destinations, both domestic and foreign. It also shows the magnitude of the flows with lines of proportional thickness.

We have also computed the values of DVA, which provide the estimates of the value added content in each export flow originating in Moroccan regions. Table 3 presents the aggregate results for both regional traded value added and regional total traded water embodied in regional exports, by main destinations. Overall, the amount of total water embodied in interregional exports surpasses that of foreign exports in the Moroccan case in a ratio of 6.4–1, i.e. for each m^3 of virtual water in foreign exports, 6.4 m^3 were traded

[8] The forthcoming analysis is concentrated in total water use.

Table 3. Regional Traded Value Added and Water in Exports, by Destination

	Value Added (million DHS)				Water (million m^3)			
Region	Domestic	Foreign	Total	%	Domestic	Foreign	Total	%
Tangier-Tetouan-Al Hoceima	16,708	12,863	29,571	6.95	1710.157	208.5223	1,919	5.88
Oriental	14,857	5,426	20,283	4.77	1706.536	278.042	1,985	6.08
Fès-Meknès	29,992	6,000	35,992	8.46	4013.509	1258.608	5,272	16.15
Rabat-Salé-Kénitra	45,848	9,029	54,876	12.89	3538.385	125.624	3,664	11.22
Béni Mellal-Khénifra	24,622	11,228	35,850	8.42	3143.977	870.6451	4,015	12.30
Grand Casablanca-Settat	107,971	49,529	157,501	37.00	7173.942	434.9512	7,609	23.31
Marrakech-Safi	37,912	4,871	42,783	10.05	3284.311	356.8999	3,641	11.15
Drâa-Tafilalet	8,992	1,162	10,154	2.39	1332.551	244.3761	1,577	4.83
Souss-Massa	23,683	2,927	26,611	6.25	2046.598	462.1765	2,509	7.69
Guelmim-Oued Noun	3,041	906	3,947	0.93	239.3182	66.03747	305	0.94
Laayoune-Sakia El Hamra	4,200	1,659	5,859	1.38	48.79467	54.90411	104	0.32
Dakhla-Oued Eddahab	585	1,642	2,227	0.52	11.91108	34.09604	46	0.14
Total	318,412	107,241	425,653	100.00	28,250	4,395	32,645	100.00

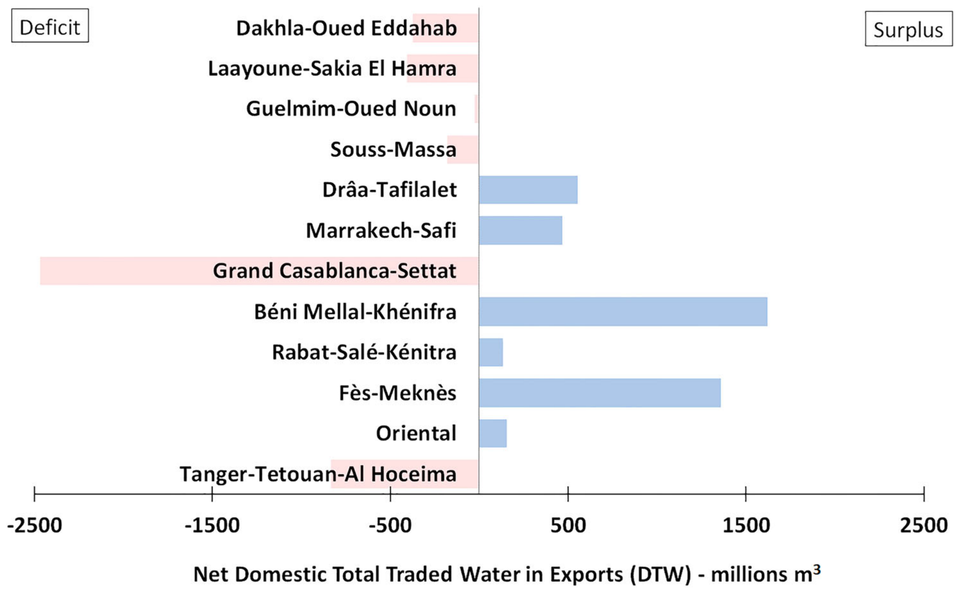
within the country.[9] Nonetheless, this ratio varies across exporting regions, ranging from 0.3 in Dakhla-Oued Eddahab, and 0.9 in Laayoune-Sakia El Hamra, both regions in the Sahara, to 16.5 in Grand Casablanca-Settat, and 28.2 in Rabat-Salé-Kénitra, the two largest urban agglomerations in Morocco.

Comparing the regional share of value added in total exports to the regional share of total traded water, we see that the contributions to value added by Laayoune-Sakia El Hamra, Dakhla-Oued Eddahab, Grand Casablanca-Settat, Tangier-Tetouan-Al Hoceima, and Rabat-Salé-Kénitra exceed their respective contributions to water. Although our water use measure does not contain any scarcity weights, as described in Section 2, these regions are associated with relative scarcity of water resources due to their structural characteristics. Relative abundance (or scarcity) of factors of production may arise from both supply and demand considerations. In our case, the scarcity of water in the Sahara explains the results for Laayoune and Dakhla. In the case of the second subset of regions, associated with the cities of Casablanca, Tanger, and Rabat, on one hand, the relative scarcity of water is associated with high levels of demand due to urbanization and the important presence of manufacturing activities. On the other hand, these regions face relative stronger agglomeration economies that potentially generate higher productivity levels of capital and labor, partially explaining, from the supply side, the relative higher value added shares in trade flows originating in these areas.

This result is in agreement with the Heckscher-Ohlin model, which predicts patterns of trade and production based on the factor endowments of a trading region: each region exports the good that makes relatively intensive use of its relatively abundant factor. Differences in factor endowments lead to differences in autarky prices, generating comparative advantage to regions where factors are relatively abundant. Since goods can be traded more cheaply than factors – factors are usually more costly to move – trade can at least partly alleviate factor scarcity. Thus, regions can import their scarce factor services embodied in goods. This seems to be the case in domestic trade within Morocco, when comparing

[9] Visentin and Guilhoto (2019) have found similar results for Brazil, where the virtual demand and supply among the Brazilian regions were also mainly interregional.

Figure 3. Net Regional Total Traded Water in Interregional Trade (million m^3).



the content of water in regional exports to that of aggregate payments to capital and labor (value added).[10]

The pattern of water content of trade within Morocco can be fairly closely associated with the physical concepts of 'water loss' and 'water savings', discussed in Hoekstra and Chapagain (2008, p. 39). Accordingly, whereas import of goods intensive in the use of water (see Table 2) implies regional water resources are saved, export of such goods entails the loss of regional water resources. That is, water used for producing commodities that are consumed in other regions is no longer available for in-region purposes.[11] Figure 3 presents the physical balance of traded water by Moroccan region. The regions with the largest deficits of virtual water in trade are Grand Casablanca-Settat and Tanger-Tetouan-Al Hoceima, followed by the two regions in the direct area of influence of the Saharan basins, namely Laayoune-Sakia El Hamra and Dakhla-Oued Eddahab. On the other hand, the regions with the surpluses with other regions are in the direct area of influence of the water-rich basins of the Atlantic with a relevant presence of agricultural activities, namely Béni Mellal-Khénifra and Fès-Meknès.

[10] Many studies have tested the H-O hypothesis that countries (regions) with a relative abundance of a resource should export that-resource-intensive goods. Following Leontief's pioneering study, who has found the opposite to hold for the USA, the so-called 'Leontief paradox' led to the publication of many follow-up tests using different approaches for different countries that appeared to sustain the paradox for international trade (Lahr & Dietzenbacher, 2001). At the regional level, though, the H-O hypothesis tends to be more frequently confirmed, as distortions usually found in international trade, such as tariffs, import quotas, government subsidies, depletion allowances, institutions, and other extraneous factors, would be minimized, while the assumption of identical production technologies and demand conditions would be met (He & Polenske, 2001).

[11] The concepts of 'water loss' and 'water savings' are approximated by our results on 'net regional total traded water in interregional trade', respectively to traded water 'surplus' and 'deficit'. We thank one of the referees for calling the attention for this point.

Table 4. Trade-Based Index of Water Intensity (**TWI**).

	R1	R2	R3	R4	R5	R6	R7	RS	R9	R10	R11	R12	RoW
R1		1.039	1.404	1.112	1.256	1.490	1.368	0.795	1.799	0.803	0.963	1.161	0.211
R2	1.242		1.794	1.158	1.583	1.631	1.637	0.777	2.189	0.786	0.993	1.230	0.668
R3	1.627	1.548		1.329	1.825	2.079	1.945	1.164	2.427	0.949	1.099	1.453	2.735
R4	0.588	0.521	0.801		0.640	1.352	0.774	0.338	1.108	0.308	0.418	0.558	0.181
R5	1.768	1.901	2.259	1.592		1.387	2.120	1.466	2.684	1.350	1.668	1.989	1.011
R6	0.774	0.887	0.962	0.852	0.841		0.951	0.713	1.066	0.620	0.476	0.819	0.115
R7	1.015	0.870	1.225	0.805	1.186	1.127		0.760	2.034	0.650	0.846	1.052	0.955
R8	1.971	1.984	2.428	1.737	2.390	1.489	2.306		2.927	1.549	2.001	2.349	2.742
R9	1.072	0.946	1.090	0.684	1.101	1.418	1.479	0.957		0.650	0.638	0.955	2.059
R10	0.845	0.745	0.945	0.601	0.942	1.212	1.037	0.582	1.337		0.731	0.910	0.950
R11	0.193	0.292	0.202	0.097	0.222	0.088	0.226	0.308	0.217	0.172		0.267	0.432
R12	0.300	0.348	0.246	0.156	0.274	0.300	0.343	0.372	0.267	0.246	0.121		0.271

R1 - Tangier-Tetouan-A1 Hoceima; **R2**- Oriental; **R3**-Fès-Meknès; **R4** - Rabat-Salé-Kénitra; **R5** - Béni Mellal- Khénifra; **R6** - Grand Casablanca-Settat; **R7** –Marrakech-Safi; **R8** – Drâa-Tafilalet; **R9**- Souss-Massa; **R10** - Guelmim- Oued Noun; **R11**-Laayoune-Sakia El Hamra; **R12**-Dakhla-Oued Eddahab; **RoW**-Rest of the World.

Note: in blue are those flows greater than 1, more intensive in domestic total traded water in exports than in domestic value added in exports; and in red are those one lower than 1, the opposite.

Finally, based on Equations 22 and 23, we have computed the Trade-Based Index of Water Intensity (TWI), which reveals the relative water use intensities associated with specific interregional and international export flows. We estimate, for trade flows associated with each origin-destination pair, measures of value added in trade and water in trade that were further used to calculate our index. The results are presented in Table 4 and point to different ratios across flows of share in total traded water to the respective share in total traded value added. Different patterns appear not only when international export flows are compared to domestic export flows, but when looking at trade flows within the country.

The regional patterns of relative factor content in trade revealed by the TWI can be grasped by reading Table 4 in two different perspectives. First, going through the rows, one can verify that values for the TWI smaller than one relative to interregional trade prevail in regions that present relative scarcity of water resources – urban agglomerations of Rabat (R4) and Casablanca (R6), as well as the desert areas in the southern part of the country. In those cases, trade flows are relatively more concentrated in terms of value added than in water content. Second, as we look at the column results, we can conclude that (i) more water-intensive trade flows directed to the areas under the influence of the Sahara basins are spatially concentrated in Fès-Meknès, Béni Mellal-Khénifra and Drâa-Tafilalet, that benefit from their relative abundance of water resources and their strategic location to access the southern areas of the country; (ii) except for sales from Casablanca and Rabat, domestic trade within the 'fish' area is dominated by more water intensive flows; and (iii) despite the documented fact that Morocco imports water in virtual form, more than it exports, so that in effect it partially depends on water resources from other countries (Hoekstra & Chapagain, 2008, p. 73), the above-unity TWI results in the RoW column suggest that international exports from Fès-Meknès, Béni Mellal-Khénifra, Drâa-Tafilalet, and Souss-Massa are responsible, in relative terms, to put more pressure on the use of domestic water resources.

5. Final remarks

Trade flows put different relative pressure to regional environmental resources in relation to their value added creation in the exporting region. In this paper, we have focused the analysis on the relative intensity in the use of water resources in regional supply chains, with attention to the water content in bilateral export flows from Moroccan regions.

In Morocco, the *Law on Water* constitutes the legal basis for the country's water policy, emphasizing, as one of its objectives, a 'coherent, flexible planning of water resource use, at both the hydrological basin level and the national level' (Royal Decree No. 1-95-154). By including a regional dimension to the analysis of embodied water use, we provide unique information that is useful for the national water policy, adding another layer to the debate raised by Lenzen and Foran (2001). Attribution of blame to specific regions can be identified and put into perspective in the context of the use of other environmental and economic resources. Moreover, there also appears to be a link between trade in water and regional economic indicators. Our results may also be used to inform policy makers about potential future stress in Morocco's water system, as different scenarios may be projected under different sets of assumptions on the model's parameters (e.g. population growth, regional household income and demand, water use technology, changes in regional technical efficiency of water use, etc.).

It is important to reemphasize that, given the notable regional divergences in terms of climatic conditions in the country, considering the average national sectoral water use coefficients for all the regions is a strong assumption that could be biasing the results and derived implications. It is important to note that the bias goes in the direction of underestimating the water content in the water-rich regions of the northern part of the country, where the use of irrigation in agriculture is more widespread. Given the strong concentration of agriculture in that part of the country, and the dominance of the water coefficient for the agriculture sector in the aggregate results, the existing bias does not alter the main conclusions of the paper. The results are thus conservative in terms of the estimated trade in water flows from the north to the south of Morocco, which should be understood, from an empirical perspective, as a hypothetical need, rather than the actual volume traded, had the national water use technology for Moroccan sector been available across the country. In spite of minimizing the regionalization issues that might have arisen had we had access to information on regionally differentiated sectoral water use coefficients at the basin level, the consequence of using national averages is that the index obtained may be offering an approximate picture of trade water intensity in Morocco. Some efforts for estimating regional data on water consumption do exist for the agricultural sector (Mekonnen & Hoekstra, 2011; Schyns & Hoekstra, 2014). In particular, for Morocco, they only provide partial information for different crops and regions. Given the importance of agriculture in the economic structure of the country as well as in its total water consumption, considering these regional differences could notably improve the results. Nonetheless, at this stage this cannot be done for all the sectors, but it reveals that efforts in data collection are part of the research agenda in the field.

Furthermore, as a follow-up of this research, the proposed index, trade-based index of water intensity (TWI), could be used to take into account other structural elements of the Moroccan economy (or any other economy). It could be compared, for instance, to similar metrics related to other natural resources. Economic activity demands different scarce resources whose availability varies across regions within a country. By using information on sectoral use of other natural resources, the integrated water-economic analysis of regional supply chains that we have discussed can be expanded. It is possible to add another layer of complexity to a system of resources management, as other trade-offs may appear involving different regional actors, further justifying the need for coordinated resources management systems.

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