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The Paradox of the Virtual Water Trade Balance in the Mediterranean Region

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Abstract: Climate change, water shortages and desertification threaten the economic and environmental sustainability in the Mediterranean. Limited rainfall and higher temperatures put agricultural production, which relies on water availability, in jeopardy. Thereupon, Mediterranean countries pursue agri-food resilience and water preservation through efficient water policies. Hence, water-deprived areas ought to import rather than produce water-intensive products to maintain water inventories and sustainability consequently. As this study examines the water sustainability for a Mediterranean water-scarce region with a particular focus on agriculture, the virtual water trade balance explores this hypothesis. A regional input–output model is constructed, and then total water consumption and the virtual water flows for each economic sector are estimated to determine the virtual water trade balance of the economy. Results indicate that the study area has a trade deficit and struggles economically but is a net importer of virtual water and secures water sustainability. As this virtual water deficit relies heavily on agriculture and originates in vast total water consumption rather than a large trade deficit, a paradox occurs; water-intensive cultivations and animals that consume 91.75% of water resources end up appearing to be water-saving. Further research is needed to strike a balance between economic growth and environmental protection.

Keywords: virtual water trade; sustainable agriculture; Leontief paradox; input–output model; Mediterranean; peri-urban agriculture

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1. Introduction

As water is a vital input for food production, efficient water governance is critical for countries that seek to build resilience against climate change, desertification and rising antagonism for food [1]. Since food production depends on water availability, food security is vulnerable to water shortages, pollution and [2]. Concurrently, environmental sustainability of water is underestimated as excessive irrigation and groundwater depletion and nitrate pollution due to agricultural activities to support food production imperil long-term viability of water inventories [3]. Notwithstanding the foregoing, the exchange of perishable goods among countries or regions and eventually trade flows, plays a significant role in food resilience which subsequently affects water resources. Recognizing the importance of water in the production process, especially for the agri-food sector, Allan (1993) developed the virtual water content or embedded water concept which is the amount of water used to produce a product, whether agricultural, industrial, or service [4]. Allan (1998) went a step further and linked virtual water content to international trade and enabled the recording of integrated water circulating between regions or countries [5]. Thus, the concept of a virtual water trade balance denotes the surplus/deficit of water use of each economic sector in a specific area. Since agriculture uses the largest amounts of freshwater among all economic sectors [6], studies focus mostly on the agricultural trade balance and eventually the virtual water content of agriculture and separate cultivations. Yang et al. (2006) built upon this concept and estimated the water use of international food trade and report that virtual water flows from high crop water productivity to low crop water productivity countries resulted in water savings globally [7]. Zhang et al. (2018) investigate trade flows of the Belt and Road regions (40 countries) that relate to China and the virtual water content of agricultural products that are traded [8]. Llop (2008) addresses the economic impacts of different water policies in the Spanish economy [9] and Brindha (2020) and Chouchane et al. (2015) underpin the importance of water trade balance in agriculture for Germany and Tunisia, respectively [10,11]. Nonetheless, scholars do not examine virtual water flows among countries only, but also between regions of the same country to assist policy makers form a coherent water policy based on maximum water productivity and adequate water resources.

Dietzenbacher and Velázquez (2007) examine the virtual water trade of Andalusia, a (NUTS−2 statistical region) in Spain with a focus on agricultural sectors [12], while Bae and Dall'erba (2018) estimate the water trade balance in Arizona, USA and develop scenarios to minimize water consumption [13]. Mubako et al. (2013) analyze the water–economy nexus of interregional trade between two US States, California, and Illinois [14]. The imbalance between water-rich and water-deprived regions in terms of virtual water trade in Iran is reported by Qasemipour et al. (2020) [15], an issue that is common in China too [16]. The Mediterranean basin is also exposed to water shortages and the resilience for most of these countries depends on imports of agricultural products rather than domestic production. Water shortages are expected to affect food production negatively by 2050 and policy makers should shift to more efficient water source management by considering the virtual water trade balance [17]. Accordingly, agriculture has to adapt to climate change through crop diversification, improved agricultural techniques and water sustainability. The United Nations, the European Union and all 21 Mediterranean countries have formulated a strategy for sustainable development and expect to achieve "economic efficiency per sector for water use" by 2016–2025 in the Mediterranean region to support rural areas that strive to maintain agricultural activities due to water shortage [18].

1.1. Peri-Urban Agriculture and Sustainability

Although traditional agriculture and virtual water flows from one country/region to another are the focal point of the relevant literature, local production systems and their impact on water consumption and sustainability are neglected. Urban and peri-urban agriculture demonstrate significant sustainability traits with short food supply chains that minimize food miles [19,20], enhance social capital [21,22] and support local economic development [23,24].

Following the founding declaration of the Brundtland Commission for global sustainable development [25], the European Union entails this commitment in the Maastricht Treaty with an aim for "economic growth and price stability, a highly competitive social market economy, aiming at full employment and social progress, and a high level of protection and improvement of the quality of the environment" [26]. It is apparent that sustainability comprises of three dimensions: social, economic, and environmental which are fulfilled by urban and peri-urban agriculture as abovementioned.

Urban peri-urban agriculture can be defined as plant cultivation (edible and ornamental) and animal husbandry in or around cities [27,28] and is practiced in various forms such as gardens, fields, terraces, and empty public spaces [29]. However, as the urban character of agriculture is easy to determine, the term "peri-urban" is fluid and not defined on the basis of specific data [30]. While van Veenhuizen (2007) argues that peri-urban agriculture is organized on a larger scale with market orientation rather than nutritional self-sufficiency [31], Riad et al. (2020) suggest the term "peri-urban green" that incorporates agricultural lands, shrubs and forests adjacent to urban areas, particularly for arid regions as in Middle East and North Africa, that have a diverse landscape where rural areas are substituted by deserts [32]. Size differences between countries and cities make it difficult to choose a single definition for peri-urban agriculture. For example, the metropolitan area of Beijing or Paris is connected to alternative food chains (AFNs) and short supply chains [24,33] to an area almost equal to or greater than a NUTS−2 Region in Europe. It is evident that peri-urban agriculture incorporates all three dimensions of sustainability and can support resilience for local economies that strive to combine economic development along environmental protection and social cohesion.

1.2. The Leontief Paradox and Water Consumption

Economic resilience is connected to the agri-food sector during crises and recessions [34]; therefore, water, which is a primary input for agriculture, plays a significant role in food production sustainability and the economy subsequently. According to the Heckscher–Ohlin theory, it is expected that a country should fully and efficiently exploit its abundance in particular inputs (natural resources, capital, labor) and export surplus goods and services.

However, Leontief (1953, 1956) rejected this hypothesis and demonstrated that the US economy, which was supposed to be the most capital-abundant country at that time, was exporting labor-intensive products and imported capital-intensive products instead [35,36]. This phenomenon, known as the Leontief paradox, revealed gaps in policy development that apply also in natural inputs that are utilized in the economy.

In this study, water is the debated input, and the main objective is to examine whether the Leontief paradox applies also to water consumption or not. Specifically, virtual water trade flows are estimated for a water-deprived Mediterranean region (Thessaly, Greece) with a particular focus on agriculture. The water trade balance is used to determine whether the regional economy falls into the water Leontief paradox or not. In parallel, the economic trade deficit is estimated to examine the classic version of the paradox. Additionally, virtual flows for each crop provide evidence on the sustainability of agricultural activities in the study area and data for policy planners as well.

The main tasks of the paper include the construction of a regional input–output (I/O) model for the Greek Region of Thessaly and the calculation of total water consumption for each sector. The I/O model is well suited for rural and regional areas as it estimates direct and indirect effects of exogenous changes and captures the impacts of imports and exports on the economy [37,38]. Furthermore, total (direct and indirect) water consumption and the virtual water imports and exports are estimated to account the virtual water trade balance of the study area. Following the classic version of the Leontief paradox, the water paradox is examined. The agricultural sector is disaggregated into the most water-intensive crops to estimate virtual trade flows for each agricultural sub-sector and potential recommendations.

The structure of this research includes the methodological overview, the construction of the applied model and the used dataset. The next step provides a profile of the study are and the following section presents the results of the research and related discussion. Finally, concluding remarks summarize this current work.

2. Materials and Methods

A handful of scholars apply input–output modelling for water studies as it unveils both direct and indirect consumption patterns and the economic model can be easily extended to account for natural resources as discussed above [7–16]. Relevant literature so far denotes that the input–output model is the most appropriate to calculate water consumption patterns with respect to the economic process (see Zhao et al. (2009) for a further discussion) [39]. Moreover, it allows for the estimation of trade flows and consequently virtual water trade when relevant data are not available.

2.1. The Classic Leontief Model and the Environmental Extension

The original study of Wassily Leontief introduced the concept of Input–Output analysis, where sectoral output x_i and final demand f_i are connected linearly [40,41]. The fundamental structure is based on a transactions table where observed economic data for every economic sector are depicted. The fundamental structure is based on a transactions table where each cell contains the intersectoral transactions (inputs) z_{ij} for each sector [42]. The ratio of an input z_{ij} for a given sector over the total output of this sector, known as the technical coefficient α_{ij} forms the basic linear equation as in Equation (1):

$$X = AX + F \tag{1}$$

If the final demand is considered exogenous, Equation (2) is solved with regard to X and can be written as:

$$x = (I - A)^{-1} \times f,\ |I - A| \neq 0 \tag{2}$$

where $(I - A)^{-1}$ is the Leontief inverse matrix and describes the total requirements (direct and indirect) of an economy to produce its total output given a specific final demand.

Leontief (1970) extended the classic model to measure the impacts of the economic process on the environment [43]. On this account, Equation (2) is augmented with an environmental vector to create a total environmental coefficients matrix E^t. The mathematical expression is demonstrated in Equation (3):

$$E^t = E^d \times (I - A)^{-1} \tag{3}$$

2.2. The Regional I/O Model

As regional I/O tables are usually unavailable due to time and cost constraints, researchers have developed techniques to construct regional I/O models based on larger, national datasets with the use of mechanical (mathematical) procedures and/or the infusion of primary data. The present study follows a hybrid approach known as Generation of Regional Input-Output Table (GRIT) [44] a mechanical procedure that combines secondary data (national I/O table) with the insertion of superior, primary data to the various steps of the process. A detailed algorithm for applying the GRIT regionalization technique can be found in Mattas et al. (2006), where a modified version of the initial GRIT, with the use of the Flegg location quotient (FLQ), is developed [45]. The use of the FLQ, an employment-based location quotient developed by Flegg et al. (1995), enables the conversion of the national technical coefficients matrix into the desired regional [46] (see Lampiris et al. (2019) for a detailed discussion [47]).

2.3. Disaggregation Scheme

The need for more detailed I/O tables that illustrate intra-industry patterns, and the inner structure of each economic sector has prompted scholars to develop several mechanical procedures to disaggregate economic sectors [38,48–51]. The aggregate sector under scrutiny is disaggregated based on primary data, such as gross output, of the consisting industries and further balancing of the newly created table [48] while the United Nations Handbook recommends a simple allocation of output based on the share of each sector, due to its simplicity, quickness, and applicability by experts [52]. In this study, the disaggregation scheme of agriculture relied on experts in the region that are aware of the structural composition of the industry. The twelve new sectors (Cotton, Maize, Durum wheat, Alfalfa, Tomato, Pear, Apple, Peach, Cattle, Pigs, Sheep and Goats, Other Agriculture) describe the most extensive and water-intensive crop cultivations and livestock in the region.

2.4. Virtual Water Content and Trade Patterns

The standard I/O model, presented in Section 2.1, is augmented by a water usage vector to estimate total water consumption (direct and indirect) in the economy as the result of the production process and is expressed mathematically as:

$$w^t = w^d \times (I - A)^{-1}$$

where w^t is the total water consumption of the study area and w^d is the water usage vector. Similar to the technical coefficients, the water usage vector w^d refers to the direct water requirements of each sector j to produce its output in monetary units and is mathematically expressed as:

$$w_j^d = w_j / X_j$$

The indirect water consumption is calculated as a residual of the total minus direct water consumption:

$$w_{ij}^{ind} = w_{ij}^t - w_j^d$$

Virtual Water Flows and the Leontief Paradox

The I/O model demonstrates the intra-sectoral linkages but also the external flows that affect the economic procedure such as import/export balance or final demand changes. In this section the virtual water trade is presented with the estimation of virtual water imports/exports for the whole economy and the virtual water trade balance as depicted in the equations below:

$$VWE_{ij} = \sum w_{ij}^t \times e_j$$

The virtual water export vector denotes the embedded amount of water that is exported outside the study area and is calculated as the sum of total water consumption w_{ij}^t multiplied by the exports vector e_j.

$$VWI_{ij} = \sum w_{ij}^t \times m_j$$

The virtual water import vector denotes the embedded the amount of water that is imported from regions outside the study area and is calculated as the sum of total water consumption w_{ij}^t multiplied by the imports vector m_j.

The virtual water trade balance (VWT) of an economy is calculated as the subtraction of virtual water imports from virtual water exports:

$$VWT = VWE - VWI$$

or alternatively as the multiplication of total water consumption and the net exports vector as in equation:

$$VWT = \sum w_{ij}^t \times \sum (e_j - m_j)$$

If the VWT is positive, then the economy is a net exporter of virtual water and the economic process consumes water resources that do not remain in the domestic area but are exported outside of it. On the contrary, a negative VWT denotes that the economy is a net importer of virtual water and does not deplete its own inventories. Nevertheless, the local economy depends on water resources outside the study area which makes it vulnerable to external pressures.

Depending on the abundance of water in the study area, the water Leontief paradox comes into effect. A water-scarce region ought to be a net importer of virtual water as it would sustain its poor inventories and enhance environmental sustainability of the economy. On the other hand, a water-abundant area should take advantage of its plethora of water sources and export water-intensive products to more arid areas. In both cases, if the respective conditions are not met, then the study area falls within the Leontief paradox.

2.5. Data

The National I/O table for Greece for 2015 which consisted of 64 sectors of economic activity was used in the GRIT procedure to obtain the regional I/O table [53]. The FLQ formula was calculated based on regional employment data that were obtained upon request from the National Statistics Service. Disaggregation of Agriculture was achieved with the use of regional output production for the various crops and livestock of Thessaly available at the Economic Accounts of Agriculture and the Annual Agricultural Statistical Survey for the year 2018 [54].

Water data for Thessaly were aggregate and could not serve the scope of the study. Therefore, a water usage vector (freshwater) with a major focus on Agriculture and its sub-sectors was constructed. Output (in tons) for each crop and animal was collected from the Hellenic Statistical Authority [55] and was post-multiplied with the related blue water footprint data described below (see Tables 1 and 2).

Water consumption data for crops were according to FAO standards but more accurate data were preferred where available [56]. For Cotton, which is the most extensive crop in the Region of Thessaly data were retrieved from Chapagain et al. (2005) [57]. Data for tomato cultivation in Thessaly were according to Evangelou et al. (2016) [58] and Mekonnen and Hoekstra (2010a) provided evidence for wheat in Spain that has a similar climate to Greece and was adapted for the study [59]. Animal husbandry was also treated with FAO standards [60]. Data for the rest of economic sectors were obtained from Eurostat database for water use [61,62]. Missing data for Greece were allocated proportionately according to the Spanish database that demonstrated a similar structure. Water consumption in physical units for every agricultural sub-sector is presented below:

Table 1. Water consumption of crops in physical units.

Sector	m^3/t	Sector	m^3/t
Cotton	1808	Tomato	27
Wheat	42	Apple	133
Maize	81	Pear	94
Alfalfa	27	Peach	188

Table 2. Water consumption of animal breeding in physical units.

Sector	m^3/t	Sector	m^3/t
Dairy cattle	2056	Goat	32
Beef cattle	630	Pig	520
Sheep	68		

2.6. Region under Study

The Region of Thessaly is geographically located at the center of continental Greece consisting of a large plain surrounded by mountains. The regional agricultural sector has an added value three times greater than the national average [54] and the local economy and social cohesion are highly dependent on agricultural activities and subsequently water resources availability.

Regional water resources are threatened by extreme irrigation and excessive fertilization and the Greek Government has issued an edict to preserve and protect these valuable inputs [63]. Almost all water consumed in the region annually (91.83%) is for irrigation purposes while drinking water (6.63%), livestock watering (0.91%) and manufacturing (0.62%) demonstrate less consumption [64].

The two main sources that provide water for Thessaly are Pinios river and the Almyros-Pelion basin (Table 3).

Table 3. Water Resources of Thessaly river basin in 2017.

Basin	Basin Surface (km^2)	Resources (Million m^3 per year)	
		Surface	Subterranean
Pinios	11,062	473.15	818.45
Almyros-Pelion	2078	25.6	104.5
Total	13,140	498.75	922.95

source: [64].

The Pinios basin suffers from excessive irrigation and nitrate pollution as it crosses the Region from end to end and supplies most of the agricultural activities. The Almyros-Pelion basin, located at the eastern side of the Region, is adjacent to the Aegean Sea and threatened by salt water as depletion of subterranean waters has allowed the sea to capture freshwater inventories. As a consequence, household consumption is in jeopardy as almost 65% of total water consumption is extracted from groundwater and poor water quality imperils social cohesion.

Undoubtedly, excessive irrigation and agricultural water use in general are the main threat for water resources in this deprived area. Below is presented some evidence about cultivated and irrigated land in Thessaly (Table 4).

Table 4. Cultivated and irrigated crop land in Thessaly (in ha, 2018).

		Crops			
in ha	**Total Crop Land**	**Arables**	**Garden Area**	**Trees**	**Vines**
Cultivated land	437,681	346,667.7	7404.1	56,820.4	105.2
Irrigated land	190,875.8	154,922.3	7385.5	24,573.1	3994.9

source: [65].

Arable land requires most water resources in Thessaly and represents 81% of the total irrigated land (Table 4) while it comprises 79% of the total cultivated area. The most extensive crops are Cotton, durum wheat and maize and pears; apples and peaches are the main permanent cultivations in the region (Table 5).

Table 5. The most important crops in Thessaly by land coverage and output in 2018.

Crop	Areas (in ha)	Production (in tons)
Cotton	86,746.5	307,360.34
Maize	23,357.6	286,838.3
Durum wheat	87,384.6	302,594.7
Alfalfa	25,971.1	309,965.3
Tomato	1112.3	60,026.3
Pear	2212.1	57,992
Apple	2935.3	60,938.4
Peach	2563.2	69,463.2

source: [65].

Among all vegetables tomato was selected for the scope of this study as it shares 54% of total vegetable production and covers 27% of garden area. To this extent, alfalfa comprises 64% of total fodder production and 49% of total fodder land.

3. Results

3.1. Total, Direct and Indirect Water Consumption in Thessaly

Water consumption in Thessaly is dominated by agriculture and its related sub-sectors with 91.75% of total freshwater being used directly and indirectly for the production of agricultural goods. This is a close estimation to the official data provided by the Ministry of Environment and Energy (see Section 2.1) for 2017 that report a 91.83% share of total water consumption for irrigation. This slight deviation is attributed to changes in cultivated land for 2018.

Animal breeding and its sub-sectors are the most water-intensive industries of the local economy and consume 60% of the total fresh water in the study area. Cattle (first overall) as expected consume the largest amount of water followed by Pigs (ranking second) and Sheep and Goats (third in water consumption).

Plant production and specifically arable crops (see Table 6) follows with Cotton (ranking fourth overall) as the most water-demanding crop which consumes twice as much as Durum Wheat (fifth overall) and four times more than Maize (eight). Furthermore, horticultural products such as Pears (14th), Apples (13th) and Tomato (17th) have a significantly lower water consumption compared to arable crops and animal breeding, thus settling them as more attractive in terms of water saving and economic remuneration.

Table 6. Total, direct, indirect water consumption in Thessaly (2018, m^3 per EUR).

Sector (Rank in Parenthesis)	Total Water Consumption	Direct	Indirect
Cotton	2.012 (4)	1.609 (4)	0.403 (4)
Maize	0.515 (8)	0.367 (8)	0.148 (7)
Durum wheat	0.966 (5)	0.740 (5)	0.226 (6)
Alfalfa	0.189 (12)	0.142 (11)	0.047 (12)
Tomato	0.006 (17)	0.004 (16)	0.002 (21)
Pear	0.027 (14)	0.023 (14)	0.004 (15)
Apple	0.107 (13)	0.083 (13)	0.024 (13)
Peach	0.367 (9)	0.253 (9)	0.114 (10)
Cattle	3.078 (1)	2.055 (1)	1.023 (3)
Pigs	3.014 (2)	1.828 (2)	1.186 (1)
Sheep and Goats	2.844 (3)	1.735 (3)	1.109 (2)
Other Agriculture	0.684 (6)	0.410 (7)	0.274 (5)
Products of forestry and related services	6.80×10^{-1} (7)	5.49×10^{-1} (6)	1.31×10^{-1} (8)
Fish and fisheries	3.06×10^{-1} (10)	1.92×10^{-1} (10)	1.14×10^{-1} (9)
Mining and quarrying	4.40×10^{-3} (19)	2.70×10^{-3} (19)	1.70×10^{-3} (18)
Food, beverage and tobacco products	4.94×10^{-3} (18)	2.70×10^{-3} (18)	2.24×10^{-3} (17)
Textiles, Clothing and leather products	1.73×10^{-3} (23)	6.09×10^{-4} (23)	1.12×10^{-3} (22)
Wood, paper, printing	1.43×10^{-2} (15)	7.59×10^{-3} (15)	6.75×10^{-3} (14)
Petroleum, chemicals, pharmaceuticals	3.60×10^{-3} (20)	1.94×10^{-3} (21)	1.66×10^{-3} (19)
Rubber and other non-metallic products	2.78×10^{-3} (21)	1.39×10^{-3} (22)	1.40×10^{-3} (20)
Metal products	2.78×10^{-3} (22)	1.97×10^{-3} (20)	8.09×10^{-4} (23)
Electric, electronical and other equipment	3.84×10^{-5} (36)	2.12×10^{-5} (36)	1.73×10^{-5} (33)
Motors and transport equipment	8.85×10^{-4} (24)	5.53×10^{-4} (25)	3.32×10^{-4} (24)
Furniture; other manufactured goods	7.57×10^{-3} (16)	4.02×10^{-3} (17)	3.54×10^{-3} (16)
Repair and installation services of machinery and equipment	5.65×10^{-4} (26)	3.97×10^{-4} (26)	1.67×10^{-4} (26)
Electricity and related activities	2.10×10^{-1} (11)	1.37×10^{-1} (12)	7.25×10^{-2} (11)
Water supply and Sewage	5.54×10^{-5} (33)	4.48×10^{-5} (33)	1.06×10^{-5} (37)
Construction	8.76×10^{-4} (25)	5.73×10^{-4} (24)	3.04×10^{-4} (25)
Trade	$1.48E \times 10^{-4}$ (29)	9.88×10^{-5} (29)	4.91×10^{-5} (28)
Transport, warehouse, postal services	4.76×10^{-5} (34)	2.58×10^{-5} (35)	2.18×10^{-5} (32)
Accommodation and food services	2.18×10^{-4} (27)	1.32×10^{-4} (28)	8.66×10^{-5} (27)
Telecommunications, Publishing, Motion picture, Computer services	3.13×10^{-5} (37)	1.86×10^{-5} (37)	1.27×10^{-5} (35)
Finance and Insurance	1.32×10^{-5} (39)	8.88×10^{-6} (40)	4.29×10^{-6} (38)
Real estate activities and imputed rents	3.34×10^{-6} (41)	3.17×10^{-6} (41)	1.66×10^{-7} (41)
Legal, Architectural and other scientific services	3.95×10^{-5} (35)	2.70×10^{-5} (34)	1.25×10^{-5} (36)
Rental, employment, travel, security services	3.06×10^{-5} (38)	1.74×10^{-5} (38)	1.32×10^{-5} (34)
Public administration and defense services	1.22×10^{-5} (40)	9.91×10^{-6} (39)	2.32×10^{-6} (40)
Education services	5.92×10^{-5} (32)	5.63×10^{-5} (32)	2.87×10^{-6} (39)
Health and Social services	2.06×10^{-4} (28)	1.57×10^{-4} (27)	4.90×10^{-5} (29)

It should be noted that water consumption in physical units varies widely in comparison with monetary units. Direct water consumption is an indicator for this difference. For instance, Durum wheat consumes almost 43 times less than Cotton in physical units (see Table 1) but only two times less in monetary units (see Table 6).

The primary sector dominates water consumption as Forestry products (7th) and Fisheries (10th) account for 6.55% of total water consumption, while from the secondary and tertiary sector, only Electricity and related activities (11th) report noteworthy consumption (1.39% share). It is remarkable that 67% is direct water consumption and 33% is consumed indirectly as a result of the economic process. All sectors demonstrate higher direct over indirect consumption except Textiles, Clothing and Leather and Rubber products that demonstrate higher indirect than direct consumption with 64.8% and 50.12% share, respectively. This is attributed to the use of these industries as inputs for other sectors.

3.2. Virtual Water Flows in Thessaly Region

The Region of Thessaly is a net importer in terms of water consumption. The virtual water trade balance is negative, thus imported embedded water surpasses exported resources. As Thessaly is a water-scarce area, the negative virtual water trade balance (VWT) satisfies initial hypothesis that Thessaly imports less abundant inputs (water) in the form of embedded products. However, this observation is a direct aftermath of the trade deficit that the study area demonstrates.

Despite the fact that more than 50% of the trade deficit (57.86%) consists of six sectors of the secondary and tertiary industries (Mining and quarrying, Food, beverage and tobacco products, Petroleum, chemicals, pharmaceuticals, Motors and transport equipment, Trade, Real estate activities and imputed rents), the virtual water deficit is an outcome of the agricultural sector mostly. Cotton (51%), Durum Wheat (10%) and Cattle (9%) are the sectors responsible for the largest shares of the virtual water trade balance (VWT) in the study area as they consume most of the water resources to produce their output (see Table 7).

Table 7. Total water exports/imports in Thessaly (2018, million m^3).

	Trade Balance (mil EUR)	VWT (mil m^3)	VWE (mil m^3)	VWI (mil m^3)
Cotton	−72.013	−127.406	71.754	199.161
Maize	−9.535	−4.066	2.977	7.043
Durum wheat	−28.044	−23.774	13.049	36.823
Alfalfa	−7.794	−2.643	2.533	5176.129
Tomato	−74.751	−0.655	0.473	1127.694
Pear	−61.456	−1.655	0.737	2391.573
Apple	−20.632	−2.016	1.072	3087.748
Peach	−6.516	−1.949	1.700	3649.498
Cattle	−9.918	−22.963	15.702	38.665
Pigs	−2.696	−5.542	6.371	11.913
Sheep and Goats	−3.268	−6.495	11.508	18.004
Other Agriculture	−4.478	−2.877	18.414	21.291
Products of forestry and related services	−5.777	−3.389	0.916	4305.511
Fish and fisheries	−0.383	−0.082	0.003	8562.036
Mining and quarrying	−426.448	−4.708	2.700	7407.878
Food, beverage and tobacco products	−174.002	−9.556	8.819	18.374
Textiles, Clothing and leather products	−16.774	−0.326	0.252	5780.714
Wood, paper, printing	−43.402	−0.697	0.171	8681.037
Petroleum, chemicals, pharmaceuticals	−502.349	−10.259	7.904	18.163

Table 7. *Cont.*

	Trade Balance (mil EUR)	VWT (mil m^3)	VWE (mil m^3)	VWI (mil m^3)
Rubber and other non-metallic products	−33.266	−0.360	0.245	604.654
Metal products	−120.824	−1.344	1.309	2653.115
Electric, electronical and other equipment	−94.626	−0.366	0.252	6182.943
Motors and transport equipment	−212.415	−0.345	0.176	5201.370
Furniture; other manufactured goods	−35.344	−0.198	0.045	2424.036
Repair and installation services of machinery and equipment	−1.994	−0.068	0.059	1277.405
Electricity and related activities	−6.456	−1.048	0.119	1167.205
Water supply and Sewage	−68.541	−1.897	1.690	3587.497
Construction	−147.259	−0.270	0.185	4552.762
Trade	−217.132	−5.642	4.949	10.591
Transport, warehouse, postal services	−73.118	−0.539	0.461	1.000
Accommodation and food services	−69.109	−0.046	0.030	7663.837
Telecommunications, Publishing, Motion picture, Computer services	−5.761	−0.068	0.056	123.738
Finance and Insurance	−55.064	−1.780	1.569	3348.735
Real estate activities and imputed rents	−288.602	−1.511	1.263	2.774
Legal, Architectural and other scientific services	−40.734	−0.873	0.746	1618.675
Rental, employment, travel, security services	−10.502	−0.113	0.090	2026.722
Public administration and defense services	−71.966	−0.001	0.000	7130.487
Education services	−18.150	−0.031	0.022	5292.727
Health and Social services	−105.816	−0.156	0.123	8083.404
Total	−3146.916	−247.718	180.442	113,492.933

In this fashion, the higher the economic deficit the less attractive the sector. However, the higher the virtual water deficit the more attractive the economic sector. It is evident that the economic trade deficit does not always comply strictly with the environmental trade deficit and the significance of the examined input (i.e., water in this study) in the production process alters the outcome of the initial hypothesis.

4. Discussion

Based on the Heckscher–Ohlin theory, it is expected that water-intensive sectors such as crops (Cotton, Durum Wheat and Maize), animal breeding (Cattle, Pigs, Sheep and Goats) and other primary sectors (Forestry, Fisheries) demonstrate a virtual water deficit, while sectors with low water consumption will be net exporters of embedded water. On the contrary, a positive virtual water trade balance will overturn the initial hypothesis and the economy of Thessaly will fall into the water Leontief paradox.

From an economic point of view, the Region of Thessaly, which is an agricultural economy, is expected to present a positive trade balance for the agricultural sub-sectors as the study area exploits its competitive advantage to increase the regional GDP with net exports of the primary sectors.

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Despite the initial hypothesis for Thessaly to be a net exporter of agricultural goods, results suggest that the competitive advantage of this rural economy is not fully exploited, and the economy falls into the Leontief paradox. The region is underachieving in all industries and reports a total trade deficit of 3.147 mil euros.

Although the agricultural sub-sectors do not have a large share in the trade deficit of the regional economy, they are considered to bring a competitive advantage in the area that eventually does not apply, as the results demonstrate. Tomatoes (−74,751 mil euros), Pears (−61,456 mil euros) and Cotton (−72,013 mil euros) are the less productive crops in the area, while Pigs (−2696 mil euros), Sheep and Goats (−3268 mil euros) and Other Agriculture (−4478 mil euros) have the lowest trade deficits among all economic sectors.

On the other hand, environmental sustainability is secured as the virtual water balance is negative both for the water-intensive sectors and the economy in general. Therefore, the Region of Thessaly falls outside the Leontief paradox and is environmentally sustainable. Cotton (−127.406 million m^3 water), Durum Wheat (−23.774 million m^3 water) and Cattle (−22.963 million m^3 water) have the largest virtual water trade deficits which, contrary to the economic perspective, is the most desirable attribute. Hence, in terms of water savings and environmental sustainability, they are the most efficient industries in the regional economy. Tomatoes (−0.655 million m^3), Pears (−1.655 million m^3), Apples (−2.016 million m^3), Peaches (−1.949 million m^3) are the agricultural sub-sectors with the lowest virtual water deficit. Though they report a virtual water deficit, they are considered the least water-saving crops to be cultivated.

Results indicate that the Region of Thessaly is struggling to maintain an economic trade balance and reports a trade deficit. It is noteworthy that all sectors have a trade deficit and Pigs, Sheep and Goats and Other Agriculture have the lowest among all economic sectors. Although agricultural sub-sectors have a marginal trade deficit, it was expected that as the regional economy possesses a competitive advantage and abundant agricultural resources, it would thrive in agricultural exports; hence, the Region of Thessaly falls into the Leontief paradox.

Contrary to the economic perspective, water sustainability is secured with a virtual water deficit. Results suggest that Cotton, Durum Wheat and Cattle are the agricultural sub-sectors with the largest virtual water deficit, and hence sustain local water inventories and import water-intensive products rather than deprive regional water inputs. Nevertheless, the virtual water trade balance is not an accurate indicator of sustainability as the abovementioned sectors consume the largest amounts of native water resources among all industries in the regional economy. The virtual water deficit emanates from vast total water consumption rather than a large trade deficit. This is sort of a paradox where water-intensive cultivations and animals appear as sustainable and water-friendly due to mathematical distortions.

This paradox is common phenomenon in the related literature though not defined, and agriculture is the sector that consumes the largest amounts of water globally. Wang et al. (2020) report that Gansu province, a water-scare region in China, is net exporter of virtual water and supplies water-abundant areas instead of importing water-intensive products [16]. Similarly, Qasemipour et al. (2020) reveal imbalances in virtual water trade among different regions of Iran with water-abundant areas importing rather than exporting water-intensive products, while water-deprived regions demonstrate opposite results [15]. Water mismanagement is also present in other countries like the USA where Mubako et al., 2013 studied two states with different water characteristics. The State of Illinois, which is water-rich, reported virtual water surplus as one would expect but California, which faces water shortages, also reported a virtual water surplus, thus undermining its sustainability [14]. Bae and Dall'erba (2018) advocate for a change in water policy in Arizona that has a virtual water surplus too, even though its inventories are limited [13]. This is the case also in Europe where Dietzenbacher and Velázquez (2007) document that Andalusia pressures its water resources to support its agricultural production and, contrary to the virtual trade hypothesis, exports agricultural products either to the rest of Spain or the world [12].

5. Conclusions

The present study intended to examine the Leontief paradox of a regional Mediterranean economy (Thessaly, Greece) both from an economic and environmental perspective. The main objective focused on the environmental aspect of the paradox and specifically water consumption. Since the study area presents a high agricultural output, a special focus was given on the water consumption of separate crops and animals.

For the scope of the study, a regional input-output model was constructed and the trade balance for each sector was estimated. The agricultural sector was disaggregated into the most water-demanding sub-sectors and total water consumption was estimated for every industry. Apart from the classic import/export balance, virtual water flows were estimated to determine the sustainability of the regional economy in terms of water consumption. Results suggest that the study area is unsustainable economically but sustainable environmentally (i.e., water consumption).

To summarize, sustainability is a complex issue as economic growth must be in accordance with environmental protection and viability. The Leontief paradox is a useful tool to determine the efficiency of an economy but requires further extensions when it comes to environmental sustainability. Therefore, the conflict between economic development and environmental protection and the optimal point of assessment require further research.

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