國立臺灣大學生物資源暨農學院農業經濟學系

碩士論文

Department of Agricultural Economics

College of Bio-Resources and Agriculture

National Taiwan University

Master Thesis

台灣虛擬水貿易的角色: 多區域投入產出分析

The Role of Virtual Water Trade in Taiwan: A Multiregional Input-Output Analysis

李傑榮

Gerome Carl L. Retamal

指導教授：張靜貞 博士

Advisor: Ching-Cheng Chang, Ph.D.

中華民國 111 年 7 月

July, 2022

doi:10.6342/NTU202201643

國立臺灣大學碩士學位論文

口試委員會審定書

Master Thesis Certification by Oral Defense Committee

National Taiwan University

The Role of Virtual Water Trade in Taiwan: A Multiregional Input-Output Analysis

台灣虛擬水貿易的角色：多區域投入產出分析

本論文係 Gerome Carl Lasco Retamal 君（R09627039）在國立臺灣大學農業經濟學研究所完成之碩士學位論文，於 2022 年 7 月 14 承下列考試委員審查通過及口試及 格，特此證明。

This is to certify that the Master thesis above is completed by Gerome Carl Lasco Retamal (Student ID R09627039) during his studying in the Department of Agricultural Economics at National Taiwan University, and that the oral defense of this thesis is passed on 14 July 2022 in accordance with decisions of the following committee members:

指導教授 Advisors：

張靜貞 Ching-Cheng Chang

口試委員 Committee members：

陳柏琪 Po-chi Chen

張國益 Kuo-I Chang

Kenneth Bicol Dy

劉瑞文 Ruey-wan Liou

Abstract

International trade plays a key role for achieving food security. However, as commodities are traded, the virtual water embedded in these commodities are also traded. In this paper, it is argued that agricultural imports not only help achieve food security, but also alleviate water scarcity. This study provides a virtual water extension of the World-Input Output Database (WIOD) 2016 release, consisting of three types of virtual water, namely green, blue, and grey, from 2010 to 2014 of 43 countries. As for Taiwan, its actual blue water data is included in the database, instead of estimations. As an application, a multiregional input-output (MRIO) analysis at both national and sectoral levels is conducted for Taiwan, which in 2021 faced its worst water shortage in the past 56 years. The overall virtual water consumed by Taiwan increased by 12% from 2000 to 2010, and as expected, Taiwan, in all types of water is a virtual water importer and is most dependent on imports of green virtual water. There is also an observed increase in blue agricultural virtual water exports. It is suggested that it may be better to decrease the blue virtual water exports instead of increasing it, so that the virtual blue water exported abroad may be reallocated to other sectors that may be in need and that would be able to generate greater productivity than the agricultural sector, particularly under water scarcity conditions. Lastly, the relationship between trade openness, food self-sufficiency, and food security index is described, wherein it is asserted that increased agricultural imports improve both food security and water scarcity conditions.

Keywords: virtual water trade, multiregional input-output analysis, food security, trade openness

doi:10.6342/NTU202201643

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1. INTRODUCTION

The positive role of trade not only in easing hunger, but more importantly in achieving food security has been studied extensively in both theoretical and empirical terms (Bouët & Laborde, 2017). However, when commodities are traded, the water embedded in those commodities are also implicitly traded. Allan (1993) introduced this concept of embedded water in traded commodities and coined the term "virtual water," or the amount of water used in the production of a certain commodity. As Hoekstra (2003) explained, if a water-scarce region imports water-intensive commodities, such as agricultural products, from another region, then the water-scarce region would be able to lessen its reliance on their own local water resources, and the region exporting water-intensive commodities would be able to benefit from export earnings. Through the concept of virtual water trade, the water-scarce region would be a step nearer toward attaining water security, as the water that would have been allocated for producing water-intensive commodities, which in this case have been imported, could be theoretically allocated for other commodities.

As Aldaya et al. (2010) pointed out, it is important to differentiate the type of virtual water in food trade as blue and green virtual water has different opportunity costs and environmental consequences. Konar et al. (2012) defines blue virtual water as the water that originates from rivers, lakes, reservoirs, ponds, or aquifers, as such it needs to be transported to the site of usage. With this infrastructure, blue water becomes a highly transportable resource that can be exchanged between water consuming sectors, such as the industry. With this infrastructure also, Yang et al. (2006) and Aldaya et al. (2010) mentioned that blue water incurs direct costs and opportunity cost, as there are other water consuming sectors, which would not be able to use the water when a certain sector consumes it. Green water is simply defined by Mekonnen and Hoekstra (2011a) as

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rainwater, or more technically as precipitation that is stored in the root area of the soil. This kind of water is relevant only to agricultural, horticultural, and forestry products, and it does not have any other competitor except the environment itself. Thus, green water is considered to have the lowest opportunity cost. On the other hand, the grey water refers to the amount of water needed to dilute a polluted water for it to meet the certain water quality standards. In this study, the grey water is also included, similar with the computation of total virtual water of Arto et al. (2016) and Tian et al. (2018). In this manner, the whole concept of the virtual water involved in the trade of commodities is captured.

However, the role of virtual water in achieving food security is not as well studied as the relationship between trade per se and food security. According to Antonelli et al. (2017), water and food security are highly interrelated with each other because food commodities require large amounts of water to be produced. This is also supported by literature where it is found that food trade is a vital condition for food security in water-scarce regions (Hanjra & Qureshi, 2010; Hoekstra, 2003; Konar et al., 2012). With the foregoing, it may be argued that when water security is achieved, it would be able to help achieve food security.

It is important to Taiwan to assess the role of virtual water in achieving food security because of its recent problems with water, which is clearly relevant in the agricultural sector, the sector that would lead to achieving food security. As mentioned by Alexoaei et al. (2021) the effects of trade in virtual water in achieving food security is important as it would enable policymakers to formulate policies related to conservation of water resources, maximization of the economic and social benefits of water, and use of water in the future. Therefore, there is a basis for studying the virtual water of Taiwan, particularly the agricultural sector.

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In the computation virtual water in this study, it will utilize multiregional input-output analysis (MRIO). This methodology is used to capture the entire amount of water that is needed in the production or consumption of a unit of a good. Generally, the MRIO analysis is used in terms of its monetary accounts, however in this case, the water-extended accounts will be used. Similarly, previous studies such as Tian et al. (2018) and Arto et al. (2016) have done this kind of study, however, they made it for a specific country or for the whole world. The one for Taiwan has yet to be explored.

In order to implement MRIO analysis, there is a need for the input-output tables with its corresponding water accounts. This study will use the World Input-Output Database (WIOD). As mentioned in Timmer et al. (2015), the WIOD, both the 2013 and 2016 release, consists of world input-output tables in current prices, and with detailed socioeconomic-and environmental satellite accounts. The 2013 release, which covers monetary accounts data from 1995 to 2011 for 40 countries and 35 sectors, has an established environmental satellite account for water from 1995 until 2009 only. However, the 2016 release, which covers monetary accounts data from 2000 to 2014 for 43 countries, lacks accounts for water. Therefore, this study updates the water accounts for the said countries, and specifically updates the blue water accounts of Taiwan using its actual data.

This study aims to determine the role of virtual water trade in achieving food security in Taiwan through MRIO analysis. The specific objectives of the study are as follows:

1. Establish the blue, green, and grey water accounts for the WIOD 2016 release for the remaining period not covered by the water accounts of WIOD 2013 release and update the water accounts for Taiwan, based on actual data;
2. Estimate the virtual water from trade of Taiwan using a MRIO analysis;

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3. Evaluate the current structure of virtual water of Taiwan, particularly the agricultural sector;
4. Describe the potential role of virtual water in achieving food security.

This study would be able to provide updated water accounts data that other researchers could use to study the world virtual water or the virtual water of other countries. Furthermore, the study would be able to assess how relevant virtual water is in achieving food security of Taiwan as it would provide how reliant Taiwan is on either virtual water exports or imports to satisfy total domestic final demand for commodities. Lastly, this study could also be used by policymakers as a basis for describing the current structure of virtual water trade between Taiwan and other countries, so that they could implement policies that would maximize gains from virtual water trade.

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2. REVIEW OF RELATED LITERATURE

This part discusses the relevant literature to this study, which includes the situation of water resources in Taiwan, the relationship between water resources and food security, the concept of virtual water trade and how virtual water is computed, and the application of an environmentally-extended multiregional input-output (MRIO) analysis, in this case a water-extended one, and with focus on its relationship on the agricultural sector and food security.

2.1. Water Scarcity in Taiwan

Taiwan, as described by Yeh and Chen (2022), is on the border of tropical and subtropical monsoon zone, where there is rainfall all throughout the year, and is characterized by varying land elevation, which causes difficulty in storing rainfall. As pointed out by Chu and Huang (2020), the yearly average rainfall is more than double of the world average, which leads to rainfall being the primary source of water resources of Taiwan. Furthermore, they also mentioned that rainfall intensity has increased although the number of rainfall days has decreased.

Overall, it may seem that Taiwan is a water abundant country given its plum rains as described above. However, given the type of terrain Taiwan has, which has implications on water management, and the impacts of climate change, Yen et al. (2019) mentioned that Taiwan is considered as water resource lacking country by the United Nations. Furthermore, according to Yang (2010) as cited in Huang and Lee (2019), even though there is abundant rain Taiwan, when its dense population is considered, the per capita yearly precipitation of Taiwan would be 20% lower than the world average. Moreover, Taiwan Water Resources Agency (2016, as cited in Lee et al., 2016), mentioned that even though amount of precipitation in Taiwan is 2.6 greater than the world average, it still ranked 19th across the world for water shortage.

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The prediction of Zheng et al. (2017) as cited inHuang and Lee (2019) seems to be accurate as they mentioned that the number of typhoons that would have an impact on Taiwan will decrease, which may have a negative effect on the water resources of Taiwan. Lin (2021) reported that Taiwan recently experienced the most serious water crisis in the past 56 years, because most of the typhoons, which are among its primary source of water, did not pass over Taiwan. Liou (n.d. as cited in Lin, 2021) also claimed that typhoons would become stronger, and pose a risk to water resources of Taiwan as 60% of its water use come from torrential rains brought about by typhoons.

2.2. Definition of Food Security

There are several definitions of food security existing in the literature. However, this study subscribes to the definition provided for by the United Nations' Committee on World Food Security, *"Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life."* Therefore, it should be clear that food security does not solely mean food self-sufficiency as other aspects need to be considered.

As a measure of food security, this study used the Global Food Security Index (GFSI) of Taiwan, as computed by Chen et al. (2015) to correlate GFSI with virtual water trade indicators. The GFSI from their study is based on the methodology used by The Economist, which releases the annual GFSI for various countries that unfortunately does not include Taiwan. The GFSI considers several aspects of food security, such as affordability, availability, and quality and safety, and it does not focus solely on food self-sufficiency, as they should be. In 2017, the initially three key issues considered by GFSI became four, with the inclusion of natural resources and resilience. This issue is considered to evaluate the exposure of countries to climate change, and their susceptibility

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to natural resources-related risks, and how these countries adapt to such kind of risks. One of the sub-issues under the natural resources and resilience issue includes agricultural water risk in both quantity and quality terms, and the rationale given for its inclusion is that overall water availability may influence agricultural water supply. However, Chen et al. (2015) was not able to incorporate in their study as it is one of the latest updates on the GFSI. This study would still use this index as it is one of the few literatures that captures food security instead of food self-sufficiency.

Alexoaei et al. (2021) studied the implications of trade in virtual water for the food security of the European Union (EU). They conducted a virtual water assessment of selected vulnerable EU agricultural imports from two different perspectives. First, they described the degree to which EU is dependent on the global green water resources, as it is embedded in the consumption of agricultural products. Second, they showed the degree of commitment to sustainability of countries where EU imports are coming from. They were able to show that the consumption of agricultural goods in the EU is highly dependent on virtual water imports. Fereres et al. (2011) also mentioned that food security has many dimensions. However, as to water availability, the question of whether there will be enough food in the future should be immediately followed by the question: Will there be enough water to produce sufficient food? They further enumerated three strategies to cope with water scarcity in the production of food. The first is to enhance water and land supply over current levels. The second is centered on boosting water productivity, either by increasing yield or by improving water usage efficiency, or both. Finally, the third solution would be to import water in the form of food, an alternative for dealing with regional water shortages that is heavily reliant on economics and global commerce.

2.3. Estimation of Virtual Water Trade

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Hoekstra and Hung (2002) asserted that water should be considered an economic good and proposed that if water were correctly regarded as an economic good, problems of water shortage, water surplus, and deterioration of water quality would be solved. They argue that clean, fresh water is a rare resource that should be treated economically. Thus, there is an urgent need to create relevant concepts and tools for this purpose.

Hoekstra and Hung (2002) also presented three different pathways of improvement to economically use existing water resources. The first pathway is at the individual level, where price charged for using water, and the use of technologies to save water are of primary concern. The second pathway happens at the sectoral level, where one must decide for which purpose should water be allocated for and the question of how the demand for water of all consuming sectors can be satisfied given a fixed and scarce amount of water. Usually, this pathway happens at the country level, where the government decides which sector receives water and by how much. Lastly, the third pathway happens at the global level, where countries import commodities made from resources that are limited within the importing country, and export commodities made from abundant resources within the exporting country. Therefore, a water-scarce country might thus aspire to import water-intensive commodities and export water-efficient commodities. This claim is supported by Islam et al. (2006) as they found that virtual water imports can alleviate stress on water resources of the importing countries.

When commodities are traded, the water embedded in those commodities are also implicitly traded. Allan (1996) introduced this concept of embedded water in traded commodities and coined the term “virtual water,” or the amount of water used in the production of a certain commodity. Reimer (2012) argued for the economic framework of the virtual water and answered the arguments of Wichelns (2010) that the trade of virtual water does not follow the Hekscher-Ohlin Trade Theory, where a country would

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most likely produce the commodity that uses its abundant resources, and that of Ansink (2010) that water-intensive products are not good predictor of trade flows. Reimer (2012) posits that the limited support from the said theory may be attributed towards itself because it does not account for other factors that may be more important when analyzing real trade data.

Another study that argued for the economics of virtual water Oki et al. (2017). They quantified the unique position of water among commodities based on its unit price and volume and found that water has an exceptionally low unit price and a massive amount of water. They were also able to establish that wealthy, but water-scarce countries minimize water consumption through virtual water imports. Lastly, they showed that countries with net virtual water exports have more water resources and income per capita, and that no country falls below a particular threshold in terms of both gross domestic product and their water resources.

As Aldaya et al. (2010) pointed out, it is important to differentiate the type of virtual water in food trade as blue and green virtual water has different opportunity costs and environmental consequences. Konar et al. (2012) defines blue virtual water as the water that originates from rivers, lakes, reservoirs, ponds, or aquifers, as such it needs to be transported to the site of usage. With this infrastructure, blue water becomes a highly transportable resource that can be exchanged between water consuming sectors, such as the industry. With this infrastructure also, Yang et al. (2006) and Aldaya et al. (2010) mentioned that blue water incur direct costs and opportunity cost, as there are other water consuming sectors, which would not be able to use the water when a certain sector consumes it.

Chini and Peer (2021) consumption of water in the production and generation of energy resources is deemed also as virtual water. They computed for the virtual water

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involved in the trade of 11 different energy commodities, fossil fuels, biomass, electricity, country to country trade from 2010 to 2018. There are also studies that use environmentally extended MRIO analysis that are specific to sectors. For example, Cazcarro et al. (2022) estimated the green and blue virtual water of internationally traded wood products. Pomponi and Stephan (2021) studied the water, energy, and carbon dioxide of the construction sector. They took note that virtual water studies are currently focused on energy and carbon dioxide, which may lead to unrecognized virtual water from the sector.

Lee et al. (2017) evaluated the virtual water export of five crops, namely barley, rice, maize, soybeans, and wheat. The virtual water is important to the main importers in Asia, which includes Taiwan, because they are highly depended on virtual water imported from only a few exporters. Lee et al. (2017) suggested to extend their virtual water trade boundary to include additional exporters and warned of serious dependency on foreign water resources, making them more susceptible to the circumstances of the exporters, such as drought and climate change.

There are also studies that have already studied virtual water embedded in specific sectors or commodities of Taiwan, usually using the bottom-up approach. For example, Huang et al. (2017) developed an estimation model of water consumption of different Taiwanese government institutions and found that educational institutions consumed the greatest amount of water. Chang (2020) used a top-down approach in computing the virtual water embedded in the production of rice in Yilan County and found that there is a crisis and water supply and it is being aggravated by the inefficient water use by the agricultural sector. Lee et al. (2016) studied the personal virtual water of Yunlin County residents and found that they induce a greater amount of virtual water compared with the world average.

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As pointed out by Yang et al. (2013) there are already several developed methods for virtual water accounting, and these methods can be categorized into two, namely bottom-up and top-down methods. As they mentioned, there is a need to determine first the difference between intermediate and final goods, to fully comprehend the difference between the two methods. Intermediate goods are defined as goods used as an input in the production of other certain goods, while final goods are goods that are immediately consumed and not used to produce other certain goods. The usual consumers of final goods may include households and governments.

With this in consideration, the Yang et al. (2013) defined bottom-up method as the computation that estimates virtual water from the smallest unit possible and then aggregating the same according to the needed scale and period. In simpler words, this methods uses virtual water intensity and the volume of trade of the commodity under study, and aggregate everything into the scale required. Feng et al. (2011) described this method as the most popular method as it is simpler and the data available is relatively good, while Chen and Chen (2013) claimed that the best feature of this method is that it provides an intuitive explanation of virtual water, and its role in the everyday lives of people, as it provides the amount of water needed, for example, rice, wheat, and coffee.

However, one of its weaknesses is that most of the studies using bottom-up method focuses on the agricultural sector, which leads to lack of data on industry and services sectors. Furthermore, the bottom-up method does not differentiate between intermediate and final goods, thus it would not be able to capture the whole supply chain.

The said weaknesses of bottom-up approach are solved by the top-down method, as it tracks the whole supply chain, either national or world supply chain, based on the framework that is used and the virtual water computed is assigned to final goods rather than intermediate goods. However, despite solving some of the weaknesses of the bottom-

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up approach, the top-down approach also has its weaknesses, such as the problem of aggregation of sectors, as it is in the data that is used in this study. In this study, all crops and livestock products are aggregated into one agricultural sector.

Chen and Chen (2013) mentioned that a one-region or a multi-region input-output (MRIO) model is the most common top-down method of virtual water accounting, as manifested by an abundance of this kind of studies. However, the same is not yet done for Taiwan, which is one of the gaps that this study intends to fill in.

2.4. Application of Multiregional Input-Output (MRIO) Analysis

The virtual water trade literature is vast. There are already some studies that have used the WIOD 2013 release in order to describe the structure of virtual water at both global and country level. Arto et al. (2016) estimated world water-related statistics using MRIO analysis, and found that globally, virtual water has been increasing, led by growing virtual water from China, India, and the European Union. They also found that the number of water-scarce countries are also increasing.

On the other hand, Tian et al. (2018) using the WIOD 2013 release conducted a multi-region input-output analysis to evaluate the changes through time of virtual water of China. They found that world virtual water increased by 1.4 times from 1995 to 2009 and that it is expected to continue this trend. They also found that both the agriculture sector and the food sector of China accounted for the largest amount of imported and exported virtual water. It was found that China is a virtual water exporter. The above claim of a continuous increasing trend of world virtual water is supported by Graham et al. (2020). They found that the trade of virtual nonrenewable groundwater would be double of its 2010 value by the end of 2050. They also observed that water-scarce regions would initially be virtual water exporters but would cease from doing so by 2050 because of depleted water sources.

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As mentioned by Tian et al. (2018), there is a possibility that the WIOD 2013 release would not be able to appropriately characterize institutional and technological changes of the regions being studied. Therefore, there is a need to use updated data that would address this limitation. As they stated, their findings contribute to the development of responsible environmental policies and the design of practical measures by providing quantitative information that clarifies and quantifies problems, as well as assessing the outcomes of policies and practical measures by understanding their effects on the sustainability of food consumption.

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3. METHODOLOGY

This part provides a brief discussion on virtual water accounting, followed by a simple explanation of the framework for input-output analysis, specifically how its application is extended to compute for virtual water. This is followed by the methodology used in the updating of the water accounts of the WIOD 2013 database.

Although there are several methods of virtual water accounting, this study uses the MRIO analysis, a top-down approach, to capture the full amount of water needed in the production and consumption of goods. Unlike its counterpart, the bottom-up approach, the top-down approach differentiates between intermediate and final goods, thus it would not be able to capture the whole supply chain and the actual amount of water needed in the whole chain. Furthermore, as Chen and Chen (2013) mentioned MRIO analysis is the most common top-down method of virtual water accounting but the same is not yet done for Taiwan, which is one of the gaps that this study intends to fill in.

3.1. Multi-Regional Input-Output Analysis (MRIO)

According to Mukhopadhyay (2018), the literature on input-output analysis has advanced from the traditional input-output framework to the inclusion of other mathematical and statistical techniques. The input-output analysis can capture the full effects to the economy, analyze at the sectoral level, and explain the supply chain linkages of scenarios that need to be simulated. With this, it has several economic applications, such as in the analysis of the service sector-related issues (Karar & Mukhopadhyay, 2018), energy economics modelling (Chaudhuri, 2018), pollution issues (Tariyal, 2018), and global value chains, and product fragmentation-related topics (Liou et al., 2016; Sikdar, 2018).

The input-output model is based on monetary transaction, which shows the inter-industry connection of different sectors present in an economy. As Qasemipour et al.

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(2020) mentioned, the MRIO is simply an extension of the general input-output model, with multiple regions taken into consideration. With heavy reference from Miller and Blair (2009) for the MRIO model, and Arto et al. (2016) for the application of the MRIO model to virtual water, the following explains the case of an MRIO model with three regions, n number of sectors, and the combination of all three types of water, represented by w. However, the same is applicable to the WIOD 2016 release, with 44 regions and 56 sectors from 2000 to 2014, which this study uses. The three main parts of an MRIO model is shown by Eq. 3.1.

$$Z = \begin{bmatrix} Z^{11} & Z^{12} & Z^{13} \\ Z^{21} & Z^{22} & Z^{23} \\ Z^{31} & Z^{32} & Z^{33} \end{bmatrix}$$ *Eq. 3.1*

$$f = \begin{bmatrix} f^{11} & f^{12} & f^{13} \\ f^{21} & f^{22} & f^{23} \\ f^{31} & f^{32} & f^{33} \end{bmatrix}$$

$$x = \begin{bmatrix} x^{1} \\ x^{2} \\ x^{3} \end{bmatrix}$$

$$x = Zi + f$$

where:

Z^{rs}: $intermediate\ matrix\ of\ deliveries\ from\ region\ r\ to\ region\ s$

f^{rs}: $column\ vector\ of\ final\ demand\ of\ s, for\ goods\ from\ r$

$x^{r} = column\ vector\ of\ gross\ output\ for\ region\ r$

$i = column\ summation\ vector\ of\ ones$

The Z matrix shows the economic flows of goods and services from region r (the producer) to sector s (the consumer), which are all expressed in monetary units for a specific year. In this matrix, it can also be said the goods and services produced by region s dependent not only on inputs from other regions but also from goods and services produced within its region at similar time periods. These sectors form part of the

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intermediate demand. There are also goods and services that are not further used as inputs but are consumed immediately. These goods and services are called the final demand, or the demand from households and the government, among others.

In this study, the total output of region r is denoted by x, while the total final demand for the commodities of region r is denoted by f. As discussed above, Z^{rs} represents the intermediate sales of region r to s. Therefore, the total output of region r is given by the summation of the intermediate sales and the total final demand, which is the last line of equation shown in Eq. 3.1.

One of the basic assumptions of input-output models is that inter-region flows from r to s entirely depends on the total output of region s, which is mathematically represented by Eq. 3.2. This is also sometimes called the technical coefficient, which represents the total direct input requirement of each region per unit output (Munroe & Biles, 2005), and is assumed as constant during a given time.

$$a^{rs} = Z^{rs}Z^{s} \qquad \textit{Eq. 3.2}$$

Given Eq. 3.2, the Leontief inverse matrix could be derived, where the equation $x = Zi + f$, can be written as $x = (I - A)^{-1}f = Lf$.

The MRIO model is extended to include water use per sector and per type of water (i.e., blue is given by *bw*, green is given by *gw*, and grey is given by *rw*) of each country, given by *w*, as shown in Eq. 3.3.

$$w = \begin{bmatrix} w^1 \\ w^2 \\ w^3 \end{bmatrix} = \begin{bmatrix} bw^1 + gw^1 + rw^1 \\ bw^2 + gw^2 + rw^2 \\ bw^3 + gw^3 + rw^3 \end{bmatrix} \qquad \textit{Eq. 3.3}$$

The water coefficients vector *v* represents the amount of water per unit of output per sector. Therefore, the amount of water required to produce goods to satisfy a certain final demand is given by Eq. 3.4, which is the multiplication of vector *v* with the Leontief matrix and the final demand matrix.

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$$\begin{bmatrix} vw^1 \\ vw^2 \\ vw^3 \end{bmatrix} = \begin{bmatrix} \hat{v}^1 & 0 & 0 \\ 0 & \hat{v}^2 & 0 \\ 0 & 0 & \hat{v}^3 \end{bmatrix} \begin{bmatrix} L^{11} & L^{12} & L^{13} \\ L^{21} & L^{22} & L^{23} \\ L^{31} & L^{32} & L^{33} \end{bmatrix} \begin{bmatrix} f^{11} + f^{12} + f^{13} \\ f^{21} + f^{22} + f^{23} \\ f^{31} + f^{32} + f^{33} \end{bmatrix} \quad \textit{Eq. 3.4}$$

The Eq. 3.5 shows the column vector for the final demand of a certain country, in this case country 1.

$$g^1 = \begin{bmatrix} f^{11} \\ f^{21} \\ f^{31} \end{bmatrix} \quad \textit{Eq. 3.5}$$

The computation of virtual water of country 1, given by *vw* is shown by Eq. 3.6. It is simply the sum of the virtual water from the computed final demand, which takes into consideration all virtual water because of the final demand by country 1.

$$vw^1 = \hat{v}Lg^1 \quad \textit{Eq. 3.6}$$

As for the computation of virtual water exported by country 1 to other countries, this is shown by Eq. 3.7.

$$vwexp^1 = (\hat{v}^1L^{11}f^{12} + \hat{v}^1L^{12}f^{22} + \hat{v}^1L^{13}f^{32}) + (\hat{v}^1L^{11}f^{13} + \hat{v}^1L^{12}f^{23} + \hat{v}^1L^{13}f^{33}) \quad \textit{Eq. 3.7}$$

As for the computation of virtual water imported by country 1 from other countries, this is shown by Eq. 3.8.

$$vwimp^1 = (\hat{v}^2L^{21}f^{11} + \hat{v}^2L^{22}f^{21} + \hat{v}^2L^{23}f^{31}) + (\hat{v}^3L^{31}f^{11} + \hat{v}^3L^{32}f^{21} + \hat{v}^3L^{33}f^{31}) \quad \textit{Eq. 3.8}$$

When exports are greater than imports, then there is trade surplus, but when imports are greater than exports, then there is trade deficit. Deficit in trade indicates that domestic water use of a country would not be able to satisfy its domestic final demand. Eq. 3.9 shows the difference between exports and imports, which is equal to water trade balance.

$$vwtb^1 = vwexp^1 - vwimp^1 \quad \textit{Eq. 3.9}$$

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3.2. Updating the World Input-Output Database (WIOD) Water Accounts

As mentioned in Timmer et al. (2015), the WIOD, both the 2013 and 2016 release, consists of world input-output tables in current prices, and with detailed socioeconomic- and environmental satellite accounts. The 2013 release, which covers data from 1995 to 2011 for 40 countries and 35 sectors, has an established environmental satellite account for water until the year 2009. However, the 2016 release, which covers data from 2000 to 2014 for 43 countries, lacks accounts for water. This paper updates the environment satellite account for water of the 2016 release, closely following Genty (2012), which is the same study that documented how the environment satellite accounts of the 2013 release were computed. The workflow for the establishment of water accounts for specific sectors in the WIOD 2016 release is as follows:

3.2.1. Sector A01 – Crop and animal production, hunting and related service

First, this study gathers the blue, green, and grey water intensities per country and per crop type $WCI_{c,crop,wx}$ as computed by Mekonnen and Hoekstra (2011a). It should be noted that these water intensities are only available as the average value for the period 1996-2005 and are in the unit of cubic meters per tonne of crop harvested. As shown in Eq. 3.10, water use estimate, $WCE_{c,crp,wx,t}$ is equal to the product of production, source from the Food and Agriculture Organization Statistical Database (FAOSTAT), and its respective water intensity.

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$$WCE_{c,crp,wx,t} = WCI_{c,crp,wx} \times P_{c,crp,t} \qquad \textit{Eq. 3.10}$$

$where$:

$c = country$

$crp = crop$

$wx = type\ of\ water$

$t = year$

$P = production$

By following Eq. 3.11, values of Eq. 3.10 are summed up together in order to arrive at the the total water use estimate per country and per type of water, $WCE_{tot_{c,w,t}}$.

$$WCE_{tot_{c,wx,t}} = \sum_{crp} WCE_{c,crp,wx,t} \qquad \textit{Eq. 3.11}$$

Results from Eq. 3.11 were adjusted in order to match the water use estimate values WCA_{MH}, computed by Mekonnen and Hoekstra (2011a). First, Eq. 3.12 is used to compute the average of $WCE_{tot_{c,w,t}}$ for the period 1996 to 2005.

$$WCA_{c,wx} = \frac{1}{10} \sum_{t=1996}^{2005} WCE_{tot_{c,wx,t}} \qquad \textit{Eq. 3.12}$$

The result of Eq. 3.12, $WCA_{c,wx}$ is used to arrive at a scaling factor $SF_{c,w}$, as illustrated by Eq. 3.13.

$$SF_{c,wx} = \frac{WCA_{MH}}{WCA_{c,wx}} \qquad \textit{Eq. 3.13}$$

Eq. 3.14 provides the blue, green, and grey water use per country for the period 2000-2009, $W_{c,w,t}$.

$$W_{c,wx,t} = WCE_{tot_{c,wx,t}} \times SF_{c,wx} \qquad \textit{Eq. 3.14}$$

Sector A01 also includes animal production. However, procedures outlined from Genty (2012) could not be replicated due to lack of data. As such, for the period 2000 to

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2009, the blue, green, and grey water use from WIOD 2013 release Sector AtB – Agriculture, Hunting, Forestry and Fishing is allocated as the water use of WIOD 2016 release Sector A01. For the period 2010 to 2014, the virtual water is based on two computations. First, the computed numbers for the crops production. This is then subtracted to the water accounts of the WIOD 2013 release. The resulting difference would be the water account for livestock from 2000 to 2009. The moving averages of these results are then used to represent the water accounts for livestock from 2010 to 2014, which are then added to the water accounts for crop production, and together would represent the Sector A01, or the agricultural sector water accounts.

3.2.2. Industry-related Sectors

Mekonnen and Hoekstra (2011b) computed the average blue and grey water use per country for the period 1996 to 2005. Since these values are aggregated as one for the whole industrial sector, the same is disaggregated in accordance with the share of various industrial sectors available in the EXIOBASE 3.8.2 of Stadler et al. (2021). After distributing the industrial water use, the average water uses for the period 2000 to 2005 per sector and per country is divided by the average output at constant prices for the period 2000 to 2005. The result of this would be the average water use for every one unit of output per sector at constant prices. Subsequently, this constant average would be multiplied with the output at constant prices for the years 2000 to 2014. The industry water uses in Taiwan and in the rest of the world is the average water intensity of the other WIOD countries multiplied by their respective sectoral output at constant prices.

3.2.3. Sector D35 – Electricity, gas, steam, and air conditioning supply

Genty (2012) used the study of Mekonnen and Hoekstra (2011c), which estimated the world average of blue water use of hydropower plants at a constant of 68 cubic meters per gigajoules. However, there are more recent studies that specifically computed

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estimates of energy water use, such as Chini and Peer (2021), which is better suited to utilize in this case. They were able to estimate the water use of electricity per megawatt hours of electricity from 2010-2018. Since the WIOD 2016 release is from 2000 to 2014, the average water use of electricity for the period 2010 to 2014, and electricity production data from IEA (2016) were used to extrapolate the blue water use for the years 2000 to 2009.

As for Taiwan, electricity production data is available but the corresponding water use of per unit of electricity is not. Therefore, the world average water use of per unit electricity production is used. On the other hand, values for the ROW were based on the average water use of electricity production of countries belonging not specifically included in the WIOD 2016 release.

3.2.4. Households

The average domestic water supply reported by Mekonnen and Hoekstra (2011b) and the average population per country used in the same study is used to estimate the household water use.

3.2.5. Limitations of the Established Water Accounts for WIOD 2016 Release

This study established the water accounts for the WIOD 2016 release, which covers 20 sectors, compared to 10 of the WIOD 2013 release. This is mainly because of the inclusion of several industry-related sectors. Despite the increase in the number of sectors, the established water accounts still face some data limitations.

Table 3.1 shows the sources of data for the water accounts. There are three primary sources of the water accounts, namely (1) the WIOD 2013 release, the data of which is available from 2000 to 2009 only, (2) the computation of the author, constrained by data availability but is mostly based on the procedures documented by Genty (2012), and (3) the EXIOBASE data. For clarification, even though the WIOD 2013 release

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covered the 1995 to 2011 period for the monetary accounts, its water accounts counterpart only available for the period 1995 to 2009. The EXIOBASE by Stadler et al. (2018) is a similar database to the WIOD. However, the former has more disaggregated sectors compared with the latter. Therefore, the former is used to supplement the data, particularly the shares of different industrial sectors on the overall virtual water of the industry. The WIOD is used instead of EXIOBASE as the former has more reliable monetary accounts and there may be computational limitations when a larger input-output database, like EXIOBASE is used for this study.

Table 3.1. Sectors with Water Accounts and their Data Source

Sector	2000-2009			2010-2014		
	Blue	*Green*	*Grey*	*Blue*	*Green*	*Grey*
A01	1	1	1	2	2	2
C10-C12	3	N/A	3	3	N/A	3
C13-C15	3	N/A	3	3	N/A	3
C17	3	N/A	3	3	N/A	3
C18	3	N/A	3	3	N/A	3
C20	3	N/A	3	3	N/A	3
C22	3	N/A	3	3	N/A	3
C23	3	N/A	3	3	N/A	3
C24	3	N/A	3	3	N/A	3
C25	3	N/A	3	3	N/A	3
C26	3	N/A	3	3	N/A	3
C27	3	N/A	3	3	N/A	3
C28	3	N/A	3	3	N/A	3
C29	3	N/A	3	3	N/A	3
C30	3	N/A	3	3	N/A	3
C31-32	3	N/A	3	3	N/A	3
D35	1	N/A	1	2	N/A	2
P85	1	N/A	1	2	N/A	2
Q	1	N/A	1	2	N/A	2
FC_HH	1	N/A	1	2	N/A	2

Legend:

1: Based on 2013 release

2: Based on authors' computation

3: Based on EXIOBASE data and authors' computation

See appendix for sector names.

It should also be noted that as an improvement, the actual water data for Taiwan from 2000 to 2014 are included in this study, which were sourced from the Taiwan Water

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Resources Agency Statistical Database. However, the green and grey water data are not available. It could have been computed had there been an existing computed specific per unit of a product water use from the literature, however as of writing, there is none. Therefore, the green and grey water data is still the same as the WIOD 2013 release, and the data for 2010 to 2014 were estimated using moving averages. Furthermore, there is no existing documentation on how the water on P85 – Education and Q – Human health and social work activities sectors were computed. Therefore, for the year 2010 to 2014 moving averages were also used.

Water accounts are simply the amount of water that is used by a certain sector without taking into consideration the water use of other countries. In this study, it is used to measure the amount of water, or the water coefficients, needed to produce one monetary unit of a product of a certain sector. First, the WIOD 2013 release is compared with the actual data for Taiwan. As Figure 3.*1* shows, there is a considerable difference between the WIOD 2013 release, and the actual water use data. It should be noted that in this comparison, the actual data for Taiwan is compared with blue water use of the WIOD 2013 release, as actual data for green and grey water use of Taiwan is not available. From 2000 to 2009, the actual blue water use is on the average 186% higher than the WIOD 2013 release.

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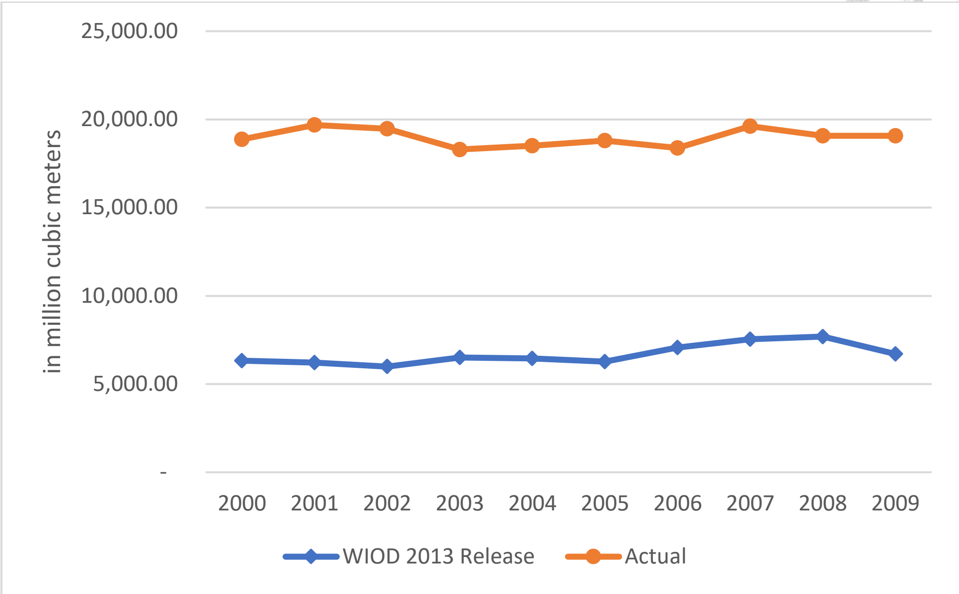

Figure 3.1. Comparison of the WIOD 2013 Release and the Actual Total Blue Water Use of Taiwan from 2000-2009

Specifically looking at the A01 sector, almost the same observations can be seen. The WIOD 2013 release underestimated the actual blue water use of the A01 sector. On the average from 2000 to 2009, the actual blue water use is 150% greater than the WIOD 2013 release. These observations support the idea of using actual data instead of the world average, which is the basis for the computation of water use for Taiwan in the WIOD 2013 release, as the world average may not necessarily be close to the actual data of a certain region. Furthermore, the total blue water use of Taiwan from 2000 to 2009 has been relatively stable through the years. As for the sectoral composition, Sector A01 – Crop and animal production, hunting and related service, hereinafter referred to as the agricultural sector, is the consistent major water user with an average of 83% of total blue water use of Taiwan from 2000 to 2009.

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4. RESULTS AND DISCUSSION

The following shows the results and discussion for this study. First, the world virtual water is discussed and compared with other studies that have computed the world virtual water. This is followed by the section for Taiwan virtual water, and then a section focused on Taiwan agricultural virtual water and its relationship with food security.

4.1. World Virtual Water

This section discusses the world virtual water and its structure, according to the type of consumption inducing the virtual water and the type of water. Figure 4.*1* shows the world, which include 42 countries and the rest of the world aggregated region, virtual water categorized into two, namely induced by domestic demand of countries and international demand for all commodities with water accounts. Overall, the world virtual water grew by 48% from 2000 to 2014. This growth is led by through trade induced virtual water, which grew by 80% from 2010 to 2014. On the other hand, domestic-induced consumption of countries grew by only 45% in the same period. Furthermore, although the domestic-induced consumption accounted for 88% of the total virtual water in 2014, the share of through trade consumption grew from 10% to 12% from 2000 to 2014. Both the increase in raw figures of the through trade consumption and its share on the overall virtual water indicate that the there is an intensification of trade of virtual water across countries.

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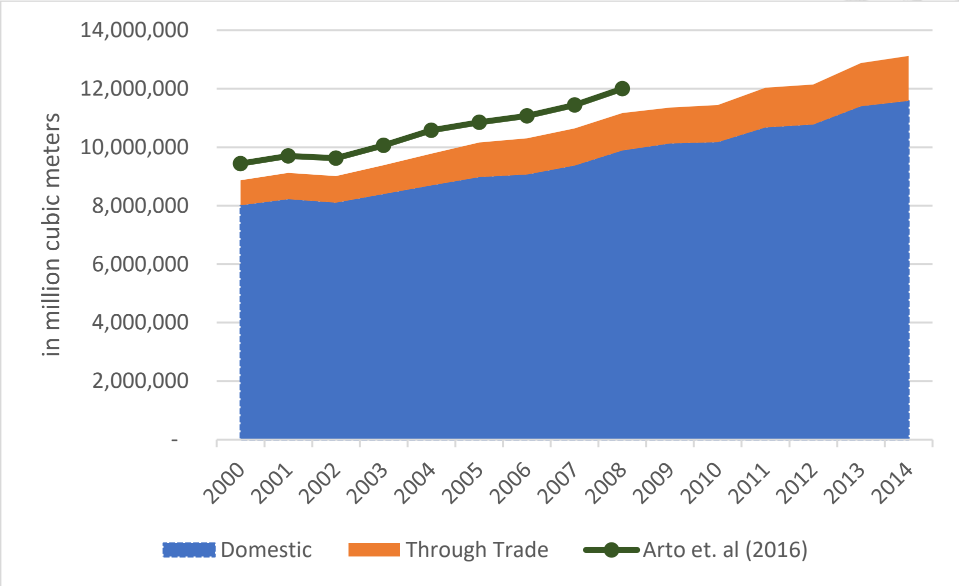

Figure 4.1. World Virtual Water by Domestic and Through-trade Induced Consumption from 2000 to 2014

Arto et al. (2016) used the WIOD 2013 release to describe the global use of water resources from 2000 to 2008. As shown in Figure 4.*1*, their computed results and the results of this study are almost similar. The difference may be attributed to the difference in the definition of virtual water, as their study included household water use in the total virtual water. This also establishes that the computed virtual water in this study is at par with the computation of existing literature. On the other hand, according to Tian et al. (2018), most of the world virtual water is induced through domestic consumption rather than trade. As shown in Figure 4.*1*, the same findings are still true even when the period was extended to 2014.

In order to fully understand virtual water, this study differentiates it into the type of water, namely, green, blue, grey. This is done because as the literature suggested, the distinct types of water have different opportunity costs. Green virtual water is the water from precipitation that is stored in the soil and used by plants. This is only relevant to the agricultural sector and thus, exhibit a lower opportunity cost compared to blue virtual

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water, which is the virtual water sourced from surface or groundwater resources. Blue virtual water includes water from reservoir and those allocated for irrigated agriculture, industry, and domestic water. Lastly, the grey virtual water refers to the amount of freshwater needed to dilute a polluted water so that it conforms with certain quality standards. As such, the blue virtual water would have the highest opportunity cost among the types of virtual water, as it may be used by a lot of other sectors. On the other hand, green virtual water can be a measure water efficiency of the agricultural sector without allocation of blue water resources.

As shown in Figure 4.*2*, the world virtual water is primarily dominated by green virtual water, followed by blue and grey virtual water, respectively. It should be noted that in the database used by this study, only the agricultural sector uses green water. Therefore, the agricultural sector already dominated the total virtual water, and may be considered as the heaviest source of virtual water.

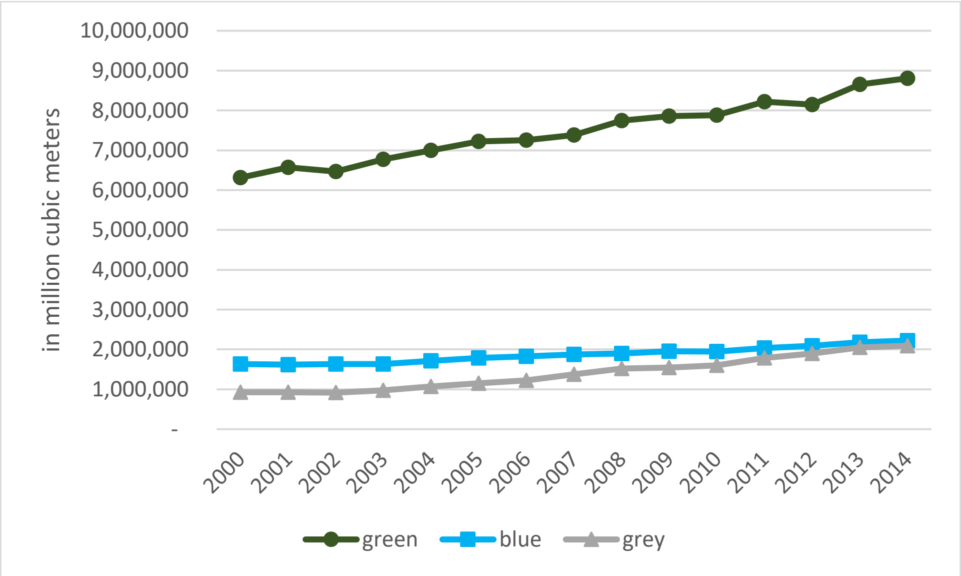

Figure 4.2. World Virtual Water by Type of Water from 2000 to 2014

However, it should be noted that the share of green virtual water from 2000 to 2014 is 71% and 67%, respectively. On the other hand, the blue virtual water exhibited a

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decrease in its share to the world virtual water from 18% in 2000 to 17% in 2014. The decrease in share of both green and blue virtual water may indicate a less reliance on green and blue water resources. However, less reliance does not necessarily mean a decrease in the amount of water resources used. This is merely a change in the mix of type of water embedded in the overall economy.

On the other hand, the grey virtual water had increased its share in total virtual water from 10% in 2010 to 16% in 2014. The increase in share of the grey virtual water is evident as its value increased to almost the same amount as blue virtual water by 2014. The increase in the amount of total grey virtual water is consistent with the findings of Liu et al. (2012) that based on a business-as-usual assumption, grey virtual water will increase over the next years. According to Mekonnen and Hoekstra (2015), some of the possible drivers of increasing grey virtual water is the increase in nitrogen input for crops in order to improve crop yield and the application of more advanced water treatment techniques, which use more water.

In this part, this study established that its computed virtual water is similar with the existing literature in terms of the total virtual water according to the source of demand (i.e., domestic, or international), and virtual water according to the type of water.

4.2. Virtual Water Allocation among Major Sectors of Taiwan

In this section, the focus is on the virtual water of Taiwan. This study will describe the structure of Taiwan virtual water, in particular the agricultural sector, according to the type of consumption inducing the virtual water, the type of water, by sectors, and the leading trade partners of Taiwan, among others.

As shown in Figure 4.*2*, the virtual water of Taiwan increased minimally from 2000 to 2014 by 12%. Furthermore, virtual water is also mostly induced by domestic demand, similar to the whole world. The share of virtual water from domestic

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consumption decreased to 16% in 2014 from 18% in 2000. On the other hand, the share of through trade consumption increased from 84% to 82% from 2000 to 2014. Consequently, the raw figures of domestic and through trade consumption grew by 10% and 23%, respectively from 2000 to 2014. The share of domestic consumption induced virtual water of Taiwan is lower than the share of world domestic consumption induced virtual water. Therefore, virtual water of Taiwan could be more affected when international consumption changes.

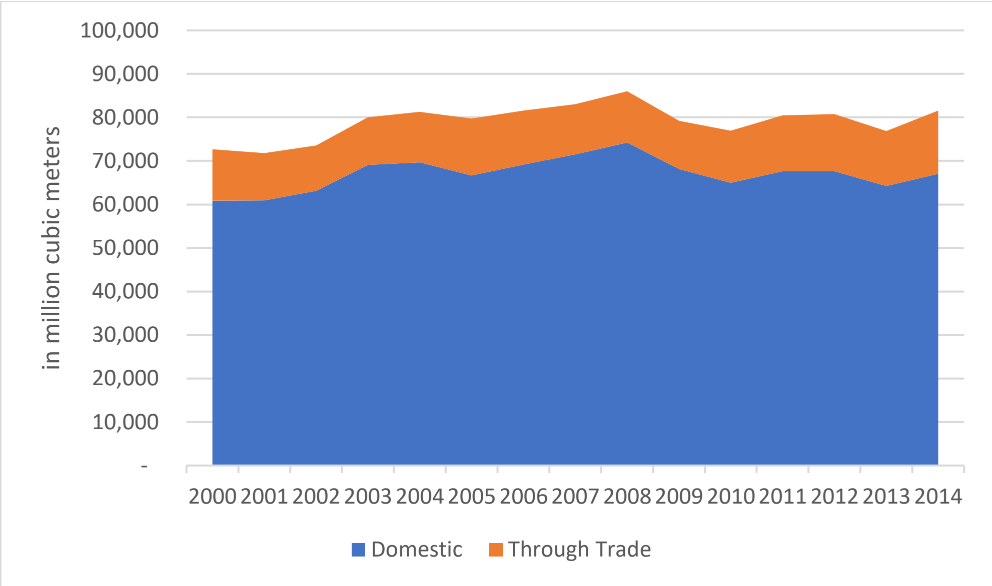

Figure 4.3. Taiwan Virtual Water by Domestic and Through-trade Induced Consumption

When the total Taiwan virtual water is categorized according to sectors. It is shown that more than 90% of virtual water is coming from the agricultural sector, as shown in Table 4.. This highlights the fact that agricultural sector of Taiwan is the primary user of water. The agricultural sector is followed by Sector D35 – Electricity, gas, steam, and air conditioning supply, with a yearly average share of 3.37% of Taiwan water use from 2000 to 2014. The remaining virtual water is shared by various industry-related sectors.

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Table 4.1. Allocation of Overall Taiwan Virtual Water by Sectors in 2000 and 2014

Sectors	2000	2014
Crop and animal production, hunting and related service activities	92.94%	91.65%
Electricity, gas, steam, and air conditioning supply	4.19%	3.11%
Manu. of food products, beverages, and tobacco products	0.51%	0.94%
Manu. of paper and paper products	0.49%	0.87%
Manu. of other non-metallic mineral products	0.18%	0.58%
Manu. of basic metals	0.36%	0.56%
Manu. of rubber and plastic products	0.26%	0.39%
Manu. of computer, electronic and optical products	0.14%	0.34%
Manu. of chemicals and chemical products	0.28%	0.33%
Manu. of machinery and equipment n.e.c.	0.15%	0.33%
Manu. of textiles, wearing apparel and leather products	0.18%	0.28%
Manu. of fabricated metal products, except machinery and equipment	0.11%	0.23%
Manu. of electrical equipment	0.07%	0.21%
Manu. of furniture; other manufacturing	0.04%	0.11%
Printing and reproduction of recorded media	0.01%	0.02%
Manu. of coke and refined petroleum products	0.07%	0.02%
Manu. of motor vehicles, trailers, and semi-trailers	0.00%	0.01%
Manu. of basic pharmaceutical products and pharmaceutical preparations	0.00%	0.01%
Manu. of other transport equipment	0.01%	0.01%
Manu. of wood and of products of wood and cork, except furniture; Manu. of articles of straw and plaiting materials	0.00%	0.00%
Human health and social work activities	0.00%	0.00%
Education	0.00%	0.00%

This study categorizes the final demand into domestically induced or through international trade. Table 4.2 shows the allocation of Taiwan virtual water because of final demand of other countries by sector. The leading sectors, namely crop and animal production, and electricity, gas, steam, and air conditioning supply, are the same with when the whole final demand was taken into consideration. However, their difference lies on the allocation of water. The share of the agricultural sector, the crop and animal production, exhibited a drop of around 6% from 2000 to 2014. The share of the industrial sectors is also increasing and is larger than the values in Table 4.. This may indicate that the international demand is driving the composition of Taiwan virtual water towards allocation to the industrial sector and less to the agricultural sector.

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Table 4.2. Allocation of Taiwan Virtual Water Induced by Final Demand of Other Countries by Sectors in 2000 and 2014

Sectors	2000	2014
Crop and animal production, hunting and related service activities	86.08%	82.74%
Electricity, gas, steam, and air conditioning supply	8.21%	5.15%
Manufacture of food products, beverages, and tobacco products	0.49%	2.81%
Manufacture of paper and paper products	0.57%	1.50%
Manufacture of textiles, wearing apparel and leather products	0.75%	1.06%
Manufacture of other non-metallic mineral products	0.30%	1.02%
Manufacture of machinery and equipment n.e.c.	0.70%	1.01%
Manufacture of computer, electronic and optical products	0.44%	0.93%
Manufacture of basic metals	0.74%	0.87%
Manufacture of rubber and plastic products	0.70%	0.85%
Manufacture of electrical equipment	0.30%	0.70%
Manufacture of fabricated metal products, except machinery and equipment	0.23%	0.51%
Manufacture of chemicals and chemical products	0.31%	0.47%
Manufacture of furniture; other manufacturing	0.15%	0.31%
Printing and reproduction of recorded media	0.02%	0.04%
Manufacture of other transport equipment	0.02%	0.02%
Manufacture of motor vehicles, trailers, and semi-trailers	0.01%	0.01%
Manufacture of coke and refined petroleum products	0.00%	0.00%
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	0.00%	0.00%
Manufacture of basic pharmaceutical products and pharmaceutical preparations	0.00%	0.00%
Education	0.00%	0.00%
Human health and social work activities	0.00%	0.00%

As shown in Figure 4.*4*, the green virtual water is still the largest source of virtual water, which remained to account for 66% and 67% of Taiwan virtual water from 2010 to 2014. It remained the same percentage despite the increase in green virtual water by 13%, increase in grey virtual water by 43%, and the decrease in blue water by 3%, all from 2000 to 2014. In this case, it can also be said the Taiwan agricultural virtual water accounts for most of the virtual water in Taiwan, as the agricultural sector is the only sector that uses green water in the database of this study. Consequently, it can be said that the share of blue virtual water from total Taiwan virtual water decreased from 24% to

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21%, and that the share of grey virtual water from Taiwan virtual water increased from 10% to 13%, all in 2010 to 2014.

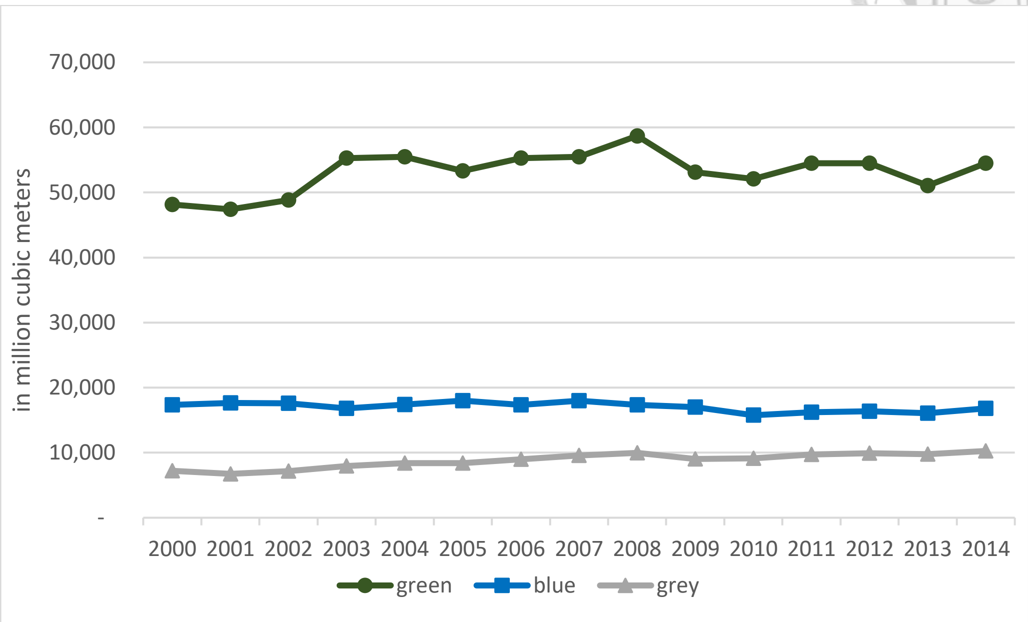

Figure 4.4. Taiwan Virtual Water by Type of Water

4.3. Taiwan Agricultural Virtual Water and its Trade

The Taiwan agricultural virtual water accounts for the largest share in Taiwan virtual water. However, despite an increase in Taiwan agricultural virtual water of 8.48% from 2010 to 2014, its share among other sectors, declined albeit minimally from 93% to 92%, from 2010 to 2014. This may indicate that other sectors are starting to account for more virtual water. One of the possible reasons to explain this may be the fact that less water is allocated to the agricultural sector, and more water is allocated to the industrial sector. It may also be the case that there has been an increasing water productivity in the agricultural sector, which led to less water needed to be allocated for this sector. However, further research on this matter is needed to fully establish that these are indeed the reasons for the decline in the share of agricultural virtual water in the total virtual water.

Figure 4.5 shows the agricultural imports and exports of Taiwan in metric tons and are graphed based on left y-axis, while the right y-axis is for the virtual water imports and

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exports. As shown below, Taiwan is a consistent net importer of agricultural virtual water from 2010 to 2014. Virtual water imports and imports in metric tons both increased from 2000 to 2014 by 14.77% and 0.98%, respectively.

However, it can also be observed that there exists an increasing trend in exported agricultural virtual water, which grew by 43% from 2010 to 2014. This could be attributed to intensification of trade as shown by Figure 4.5, where there is an increase in the weight of exports of commodities.

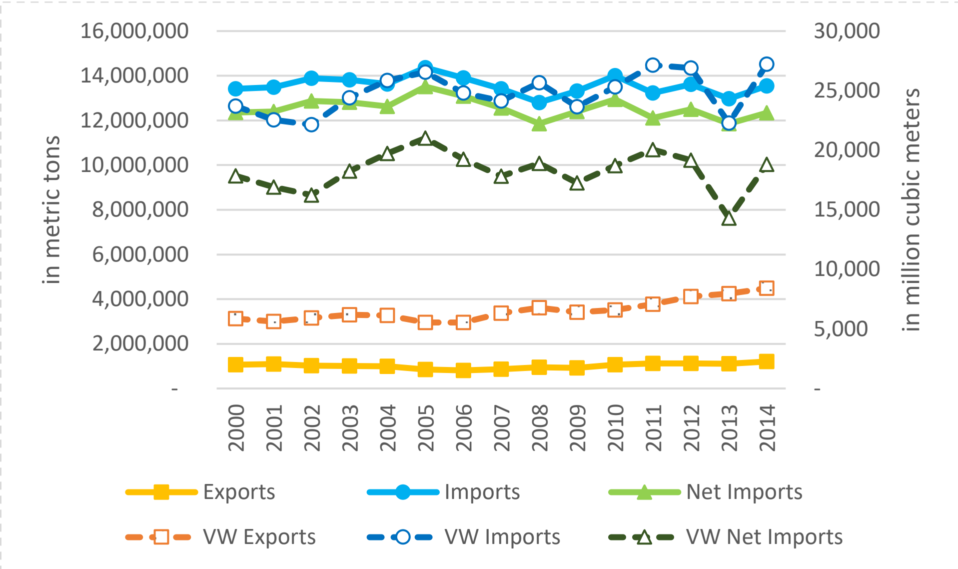

Figure 4.5. Imports, Exports, and Net Imports of Agricultural Commodities and Agricultural Virtual Water in Taiwan from 2000 to 2014

As shown by Figure 4.6, Taiwan is a net importer of agricultural green virtual water. However, the exports of agricultural green virtual water is also increasing and grew by 47% from 2000 to 2014.

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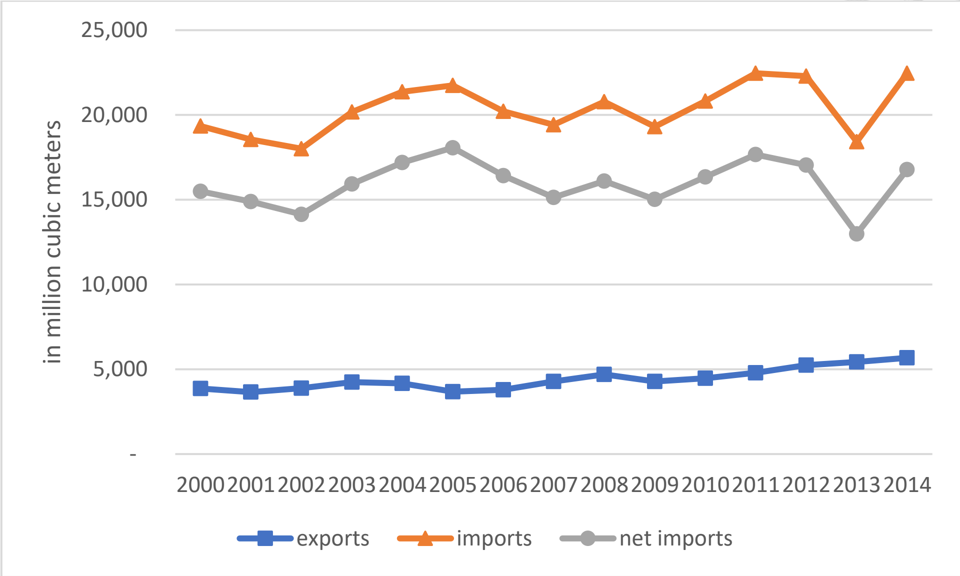

Figure 4.6. Taiwan Agricultural Green Virtual Water Imports, Exports, and Net Imports from 2000 to 2014

In terms of agricultural blue virtual water, Taiwan is still a virtual water importer, as shown in Figure 4.7. However, net virtual water imports are at a relative decline due to increasing virtual water exports thus, gap between imports and exports are getting narrower. Taiwan also almost became a virtual water exporter in 2013 due to a fall in virtual water imports. However, much consideration should be given to the trend of increasing blue virtual water exports. As mentioned before, the blue virtual water has the highest opportunity cost among the types of virtual water. The opportunity cost of allotting blue water for agricultural sector should be given a second look if the same water could be just imported through virtual water, and when there are other sectors, such as the industry, which could provide a higher return per unit of water consumed.

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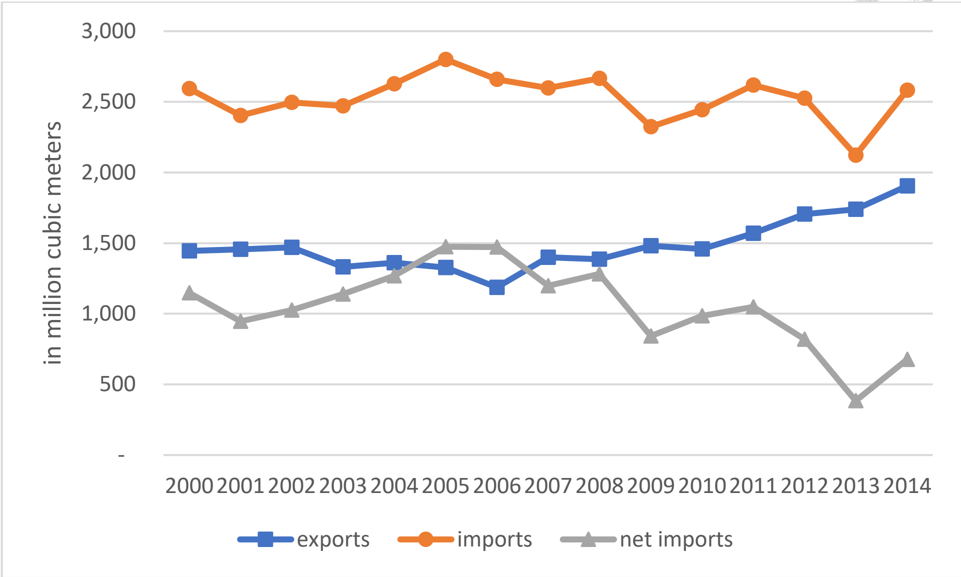

Figure 4.7. Taiwan Agricultural Blue Virtual Water Imports, Exports, and Net Imports from 2000 to 2014

In order to determine the level of dependence of Taiwan on foreign water resources, this study follows Hoekstra and Hung (2002) to solve for the virtual water import dependency of Taiwan, which is the ratio between net agricultural virtual water imports over the difference of total agricultural virtual water needed to satisfy the final demand of Taiwan and Taiwan agricultural virtual water exports. The imports dependency ratio, by definition, ranges between zero and one. A value of zero indicates that virtual water imports and exports are equal or balance, or that net virtual water export exists. However, if the ratio reaches one, the country is almost entirely dependent on virtual water imports. As shown in Figure 4*.8*, the imports dependency ratio of Taiwan decreased from 0.41 to 0.40, from 2000 to 2014. This indicates that to satisfy the demand within Taiwan for agricultural virtual water, Taiwan has been less reliant on foreign virtual water. The largest imports dependency ratio is observed in green virtual water, which indicates that Taiwan is most reliant on foreign green virtual water resources. This also suggests that most of the virtual water imports of Taiwan would be sensitive to the green water productivity of the agricultural sector of its virtual water trading countries. Gilmont et al.

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(2015) proposed that in using green water, the significant potential for improvement in rainfed agriculture should be realized through better agricultural methods and practices.

On the other hand, Taiwan is least reliant on grey and blue virtual water imports to satisfy demand within the country. It may be argued that as a water-scarce country, Taiwan is better of importing blue virtual water, instead of exporting such a high opportunity cost type of water because theoretically, such water could have been allocated to other sectors. However, the efficiency of allocation of virtual blue water or blue water itself may be further examined in other studies. This section has been able to establish that Taiwan is a virtual water importer across all type of virtual water.

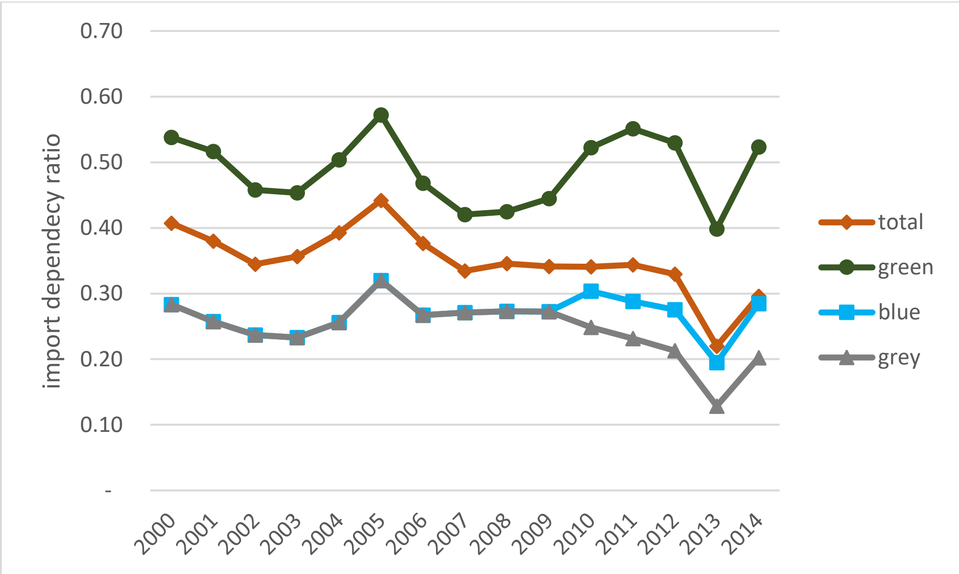

Figure 4.8. Taiwan Agricultural Total, Green, Blue, and Grey Virtual Water Imports Dependency Ratios from 2010 to 2014

As shown in Table 4.3, from 2000 to 2014, the USA accounted for 23% and 17%, respectively, of the overall agricultural virtual water imports of Taiwan. Although throughout the time series, the USA maintained its status as the top source of agricultural virtual water imports, its share has been relatively decreasing. Such decrease in share is also evident with Australia, which accounted for 11% of overall agricultural virtual water imports of Taiwan in 2000 and declined to 3% in 2014. The share of these countries was

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then transferred to other countries such as, Brazil and China, which grew from 2% to 13% and 4% to 9%, respectively from 2000 to 2014.

Table 4.3. Top 6 Sources of Overall Agricultural Virtual Water Imports of Taiwan in by Percentage Share

Countries	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
USA	23%	22%	22%	21%	19%	20%	21%	27%
Brazil	2%	4%	4%	8%	11%	6%	6%	4%
China	4%	3%	5%	5%	5%	6%	7%	8%
India	2%	2%	2%	2%	3%	3%	3%	3%
Australia	11%	10%	8%	7%	7%	7%	4%	3%
Indonesia	3%	2%	2%	3%	2%	3%	3%	3%

Countries	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
USA	26%	27%	21%	17%	16%	13%	17%
Brazil	4%	9%	10%	12%	17%	14%	13%
China	7%	7%	8%	7%	8%	9%	9%
India	6%	3%	3%	3%	4%	5%	4%
Australia	5%	4%	4%	4%	4%	4%	3%
Indonesia	3%	3%	3%	3%	3%	3%	3%

As shown in the previous figures, Taiwan is a virtual water importer, regardless if it is green or blue virtual water. In Table 4.4 and Table 4.5, Taiwan is becoming less reliant on green and blue agricultural virtual water imports from the USA and Australia. The opposite is true with the green and blue agricultural virtual water from Brazil and China, which showed an increasing reliance therefrom.

Table 4.4. Top 6 Sources of Green Agricultural Virtual Water Imports of Taiwan by Percentage Share

Countries	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
USA	22%	21%	21%	20%	17%	18%	20%	25%
Brazil	2%	5%	5%	9%	13%	7%	7%	4%
China	3%	3%	4%	4%	4%	5%	6%	6%
Australia	11%	10%	8%	8%	7%	7%	4%	3%
Indonesia	3%	2%	3%	3%	3%	3%	3%	3%
India	2%	2%	2%	2%	3%	2%	3%	3%

Countries	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
USA	24%	25%	20%	16%	15%	12%	16%
Brazil	5%	11%	11%	14%	19%	15%	15%
China	6%	6%	6%	6%	6%	7%	7%
Australia	5%	5%	4%	4%	4%	4%	3%

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Table 4.4. Top 6 Sources of Green Agricultural Virtual Water Imports of Taiwan by Percentage Share

Indonesia	3%	3%	3%	3%	3%	4%	3%
India	5%	2%	3%	3%	3%	4%	3%

Table 4.5. Top 6 Sources of Blue Agricultural Virtual Water Imports of Taiwan by Percentage Share

Countries	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
USA	22%	22%	21%	22%	20%	20%	21%	26%
China	4%	4%	5%	5%	6%	7%	8%	8%
India	4%	5%	5%	4%	7%	6%	6%	7%
Australia	11%	11%	10%	6%	6%	6%	6%	3%
Brazil	1%	1%	1%	2%	3%	2%	1%	1%
Indonesia	1%	1%	1%	1%	1%	1%	1%	1%

Countries	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
USA	25%	27%	23%	19%	18%	13%	18%
China	8%	8%	9%	8%	9%	10%	10%
India	13%	6%	7%	8%	10%	11%	8%
Australia	3%	4%	3%	4%	5%	4%	4%
Brazil	1%	2%	2%	3%	4%	3%	3%
Indonesia	1%	1%	1%	1%	1%	1%	1%

The WIOD 2016 release does not disaggregate the data for the agricultural sector at the commodity level, instead it is categorized into three only, namely, crop and animal production, hunting and related service activities, and forestry and logging. In this study, the water coefficients were computed at the commodity level, then aggregated into the crop and animal production sector.

In order to have more insights into potential commodities that compose the virtual water imports, this study presents Table 4.6, which shows the major commodities imported by Taiwan from the major sources of its virtual water imports. It can be observed that in terms of both blue and green virtual water, USA is the largest source of virtual water. However, Taiwan is more reliant with green virtual water from Brazil, compared with blue water from the same country. The commodities involved in trade between Taiwan and Brazil has been fairly consistent from 2000 to 2014, as presented in

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Table 4.6. However, the share of Brazil in the green virtual water imports of Taiwan has been increasing, which may indicate increasing amount of traded goods or increasing virtual water, or more water is used to produce a similar amount of goods as before. Furthermore, in terms of these products, it is possible that Taiwan may be affected more by changes in crop water productivity and changes in the environment of the agricultural sector of Brazil.

Table 4.6. Top Commodities Imported from the 2014 Top Sources of Virtual Water Imports in 2000 and 2014

Country	**2000**	**2014**
US	corn, soybean, leather from cattle, wheat, cattle	soybean, corn, wheat, cattle, leather from other products
Brazil	soybean, leather from cattle, other citrus, coffee and other products, green coffee	soybean, corn, leather from other products, green coffee, leather from cattle
China	feather and down, Chinese herbal medicines, leather from cattle, Jilin ginseng, melon seeds	feather and down, Chinese herbal medicines, leather from cattle, vegetables and other products, livestock-feed by-products
India	Oilseed cake and oil residue, sesame, agriculture-feed by-products	Cotton, sesame, oilseed cake and oil residue, corn
Australia	Wool, cattle, milk powder and nuggets, rough and refined sugar, sheep	Cattle, wheat, sheep, rough and refined sugar, milk powder and nuggets
Indonesia	Fruits and other products, green coffee, cotton, coffee and other products, confectionary	Green coffee, molasses, livestock-Chinese herbal medicine, baking cakes

On the other hand, Taiwan is more reliant with blue water from India compared with green water from the same country. In terms of these products, it may be possible that Taiwan would be more affected by any reallocation of water in India as the products involved are reliant on blue virtual water, which can be reallocated to other sectors. Furthermore, the major imports of Taiwan from US and Brazil are almost similar, which consists of soybean, corn, and leather. This may indicate that these products are the

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primary drivers of virtual water imports. It may be the case that these products are water-intensive or that they share a large amount over the total amount of traded goods.

As shown in Table 4.7, in terms of virtual water exports, in 2014, Japan accounted for the largest share in Taiwan agricultural virtual water exports at 19%. It is followed by China, USA, and S. Korea at 14%, 12%, and 4%, respectively. The major destinations of Taiwan virtual water exports are similar regardless of the type of virtual water, green or blue. The same major countries had been the major destinations of blue agricultural virtual water exports of Taiwan since 2000. However, it should be noted also that the total share of these major exporters is getting lower, which indicates a greater diversification of trading partners.

Table 4.7. Top 5 Destinations of Agricultural Virtual Water Exports of Taiwan by Percentage Share

Countries	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Japan	31%	29%	29%	26%	37%	35%	28%	24%
China	7%	7%	7%	7%	6%	6%	7%	7%
USA	23%	22%	22%	22%	19%	18%	17%	17%
S. Korea	1%	2%	3%	3%	2%	2%	2%	2%
Canada	2%	2%	2%	3%	2%	2%	3%	3%

Countries	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
USA	24%	23%	23%	23%	22%	21%	19%
China	7%	9%	10%	11%	12%	15%	14%
India	15%	14%	12%	11%	11%	11%	12%
Australia	2%	3%	3%	3%	3%	4%	4%
Brazil	3%	3%	3%	3%	2%	3%	2%

In order to have more insights into potential commodities that compose the virtual water exports of Taiwan, this study presents Table 4.8, which shows the major commodities exported by Taiwan to major destinations of its virtual water exports. Although commodities exported to Japan had been slightly different from 2000 to 2014, the virtual water exported to the same has been stable. On the other hand, the virtual water exports to China exhibits an increasing trend, and the exports to the same now include baking cakes, alcohol, and feather and down. Based on the exports of Taiwan in 2014, it

doi:10.6342/NTU202201643

would seem like that a number of commodities exported by Taiwan in terms of virtual water are not food commodities, like soybeans, corn, and wheat, but are most likely to be feather and down and moth orchids, among others.

Table 4.8. Top Commodities Exported to the 2014 Top Destinations of Taiwan Agricultural Virtual Water Exports in 2000 and 2014

Exports	**2000**	**2014**
Japan	Feather and down, wool, edamame, banana, vegetables, and their products	Feather and down, edamame, moth orchids, wool, oncidium
China	Leather from cattle, leather from pig, watermelon seeds, seeds, germs and fruits for planting, flowers, and their seedlings	Leather from cattle, leather from other products, baking cakes, alcohol, feather and down
US	Feather and down, confectionery, pasta, mushroom, baking cakes	Moth orchids, baking cakes, confectionery, vegetable oil, pasta
S. Korea	Wool, flowers and their seedlings, skins from pigs, fruits, feather and down	Feather and down, flowers and their seedlings, baking cakes, fruits and their products, mango
Canada	Pasta, sugar, baking cakes, rice, fully or partially fermented tea	Baking cakes, fruits and their products, feather and down, moth orchids, vegetable oil, pasta

4.4.Taiwan Agricultural Virtual Water and Food Security

In this section, this study argues that agricultural imports have two benefits. First, it helps in improving food security. Second, the water embedded in those agricultural imports, the virtual water, also helps in alleviating the water scarcity conditions in Taiwan. As established at the initial part of this study, Taiwan is a water-scarce country and encountered a severe drought the past year. Furthermore, it has been established that the agricultural sector consumes a lot of water and represents a major allocation in Taiwan virtual water. This part investigates the relationship between trade openness, food self-sufficiency ratio (FSSR), food security index, and agricultural virtual water imports.

Trade openness index is defined as the ration between total trade volume over the total gross domestic product, where trade volume refers to the sum of exports and imports. Based on the data from the Taiwan Council of Agriculture, in Figure 4.*9*, it is shown that

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Taiwan has been more open to trade when the values from 2000 to 2014 are compared. This is presented to support the proposition of Fader et al. (2013), as advocate for intensification of international trade. Aside from the potential of virtual water imports in alleviating water scarcity constraints, they push for intensification of international trade so that countries can get lower prices and access goods not available within their country. Fader et al. (2013) further asserted that the said preferences, including the economic concepts of "comparative advantage, economies of scale, technology, capital, and labor costs," are stronger drivers of trade compared to natural resources, such as water. With this in consideration, increasing trade openness may potentially alleviate water scarcity constraints of Taiwan through the virtual water embedded in its imports.

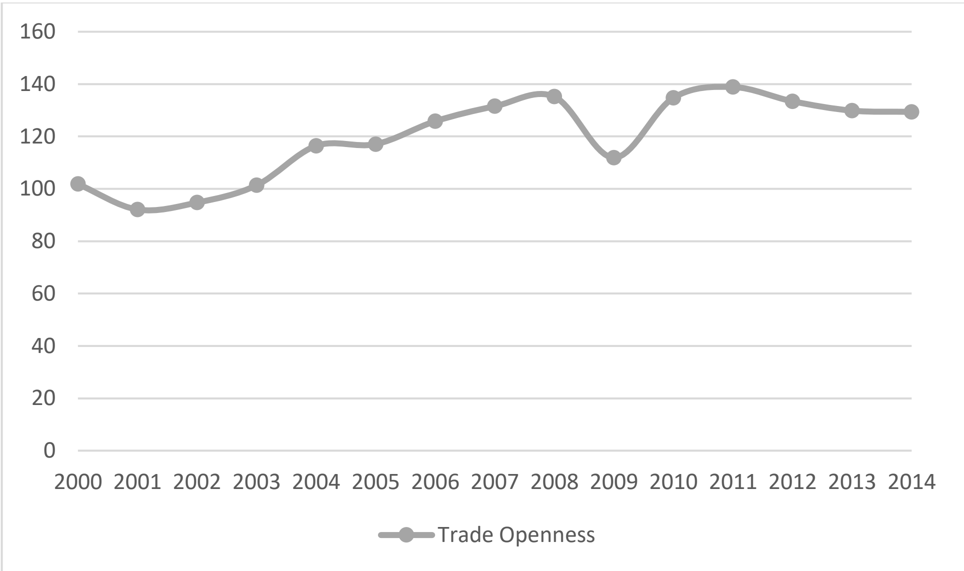

Figure 4.9. Trade Openness Index of Taiwan from 2000 to 2014

Fader et al. (2013) mentioned that several countries are not food self-sufficient because of natural resources constraints, such as water and land. In Figure 4.*10*, the food self-sufficiency ratio of Taiwan is plotted based on the data from Chen et al. (2015). The FSSR of Taiwan has been on a decline from 2002 to 2005, and now seems to be in an increasing trajectory from 2005 to 2014. However, it should also be mentioned that using FSSR as a measure may be taken as somewhat crude as it only covers one dimension,

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which is availability of food. Clapp (2017) defines this indicator as the one focusing on supply and as the measure of the capacity of a country to produce enough food to satisfy its own needs.

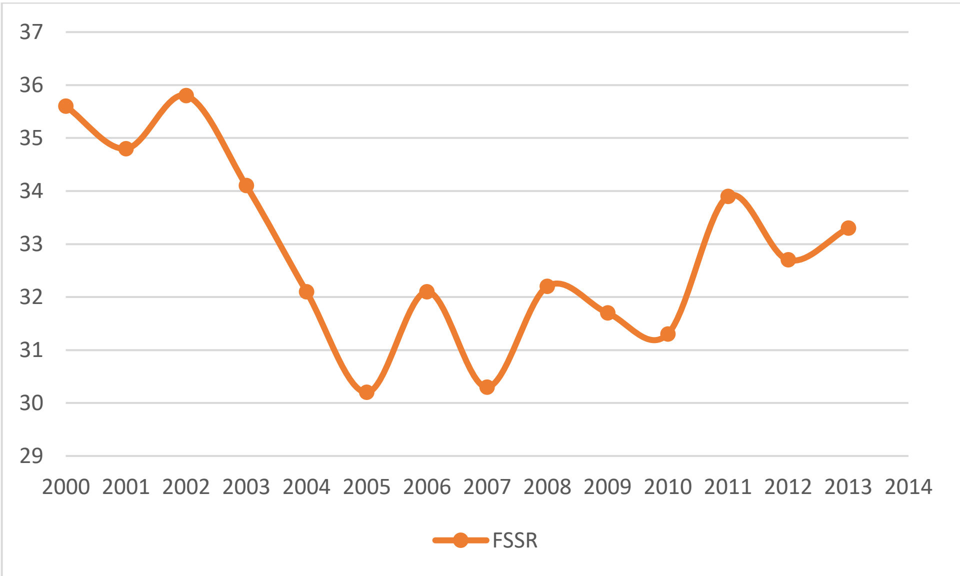

Figure 4.10. Food Self-Sufficiency Ratio of Taiwan from 2000 to 2014

However, there are other aspects of food that affects its consumption, such as its affordability and quality and safety. Therefore, it could be argued that food security may be the better indicator as it takes into account such said aspects. Chen et al. (2015) have already asserted and as shown in Figure 4.11, the Global Food Security Index (GFSI) of Taiwan showed an upward movement in the past decade. With the intensification of trade, the GFSI index seemed to follow the same trend, which has been stably increasing. This may be considered the first benefit of greater openness to trade, or more agricultural imports. However, in this study, it is asserted that there is a secondary benefit to such greater agricultural imports, which is its potential to alleviate the water scarcity condition in Taiwan. It has been said that the agricultural sector of Taiwan consumes a significant amount of water. If such water were instead imported, the water that would have been consumed by Taiwan agricultural sector can then be used by other sectors.

doi:10.6342/NTU202201643

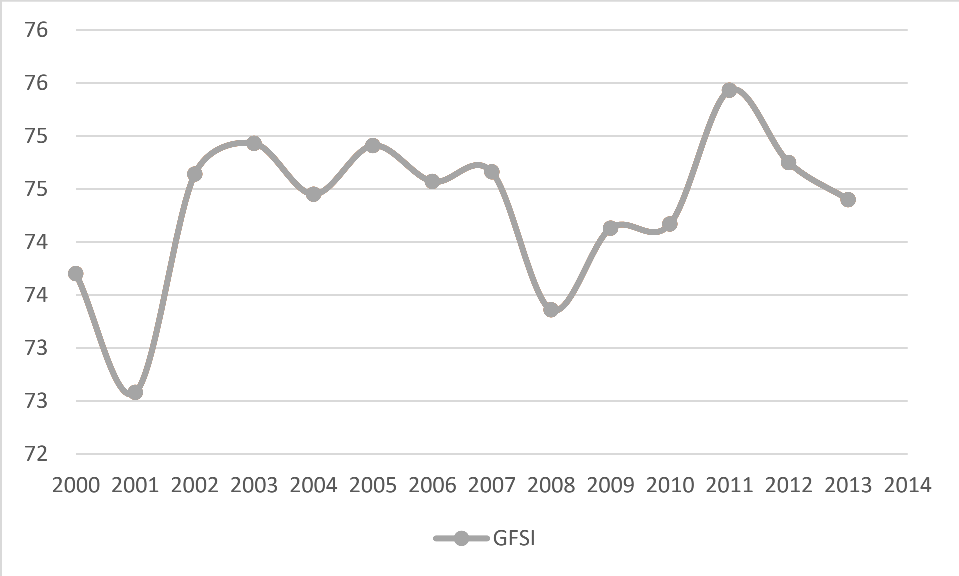

Figure 4.11. Global Food Security Index (GFSI) of Taiwan from 2000 to 2014

This last section introduced the concepts of trade openness, FSSR, and GFSI, and then proposed the potential of increasing trade openness and of greater agricultural imports as a method of alleviating water scarcity conditions in Taiwan as the agricultural imports have water embedded therein. Therefore, instead of producing such commodities in a country experiencing water scarcity, like Taiwan, the same could be imported from other countries, and the water that would have been used in locally producing such commodities may be reallocated to other sectors.

doi:10.6342/NTU202201643

5. CONCLUSION

In this study, the role of virtual water trade on the food security of Taiwan is explored through an environmentally multiregional input-output (MRIO) analysis. The selected country of focus is Taiwan as it has recently faced the worst drought in its history. Such water scarcity condition is assumed to influence the agricultural sector, and consequently to achieving food security. As such there is a need to look at the potential benefits of increasing agricultural imports in achieving both food security and alleviating water scarcity conditions.

The water accounts for the WIOD 2016 release are first established and the actual data for Taiwan was used instead of the world average values that was applied to it for the WIOD 2013 release. Therefore, actual data for Taiwan, and update data for other countries are available. It was found that the WIOD 2013 release severely underestimated the water use of Taiwan. Along with Taiwan, the data of other countries are also updated, therefore it may be used by other researchers to explore their respective virtual water.

Furthermore, the virtual water of Taiwan is computed and classified according to domestic, and through-trade induced consumption, and green, blue, and grey types of virtual water. It was found that the virtual water of Taiwan increased minimally from 2000 to 2014 and that it follows the same structure of virtual water as the world, which is dominated by domestic-induced consumption and by green virtual water. The same conclusions were also found in existing literature.

In terms of imports dependence, it is established that Taiwan has been a virtual water importer across all types of water from 2010 to 2014 and that Taiwan is most dependent on foreign green virtual water resources, followed by grey, and blue. This means that Taiwan would be more sensitive to the water use and productivity of rainfed

doi:10.6342/NTU202201643

agriculture of foreign countries. An improvement in this aspect may lead to lower amount of virtual water imports for Taiwan.

On the other hand, in terms of exports, Taiwan has posted increasing amounts of blue virtual water exports. Furthermore, as the literature claims, there are still benefits from trading goods that a particular country has a comparative advantage over other countries based on the resources that are abundant in their respective territories. Taiwan, as a water-scarce country, it may be theoretically better to decrease the blue virtual water exports instead of increasing it, so that the virtual blue water exported abroad may be reallocated to other sectors that may be in need and that would be able to generate greater productivity than the agricultural sector, particularly under water scarcity conditions. Furthermore, through improving water productivity in agriculture, the water that would have been used by the agriculture sector and exported to other country could be made available to other industries that have a higher productivity per drop of water. Moreover, importing virtual water, instead of exporting it, could help reduce the need to use more land for farming and the environmental costs associated therewith, in cases such as Taiwan with an already limited land suitable for agriculture.

Lastly, the two potential benefits from increased trade openness, or in this case increased agricultural imports. First, as established by other studies, increased agricultural imports help achieve food security. The second benefit is that the virtual water embedded in those agricultural imports could be of help in alleviating water scarcity conditions in Taiwan. Overall, the virtual water trade provides new insights on the use of water resources of countries and sectors worldwide. At the very least, it can provide policymakers an idea of how water is used within a country and how it is traded across the world. Furthermore, it cannot be denied that water is an important input to the agricultural sector. Consequently, its efficient use bears heavily on food security. As such,

doi:10.6342/NTU202201643

further studies on the relationship between virtual water trade and food security is encouraged so that water-scarce countries can improve their food security and that water-abundant countries can better use their water resources taking into consideration sustainable and efficient allocation and use of the limited water resources worldwide.

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Appendices

Table 1. WIOD 2016 Release Sector Code and Names

Code	Sector
A01	Crop and animal production, hunting and related service activities
A02	Forestry and logging
A03	Fishing and aquaculture
B	Mining and quarrying
C10-C12	Manufacture of food products, beverages, and tobacco products
C13-C15	Manufacture of textiles, wearing apparel and leather products
C16	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
C17	Manufacture of paper and paper products
C18	Printing and reproduction of recorded media
C19	Manufacture of coke and refined petroleum products
C20	Manufacture of chemicals and chemical products
C21	Manufacture of basic pharmaceutical products and pharmaceutical preparations
C22	Manufacture of rubber and plastic products
C23	Manufacture of other non-metallic mineral products
C24	Manufacture of basic metals
C25	Manufacture of fabricated metal products, except machinery and equipment
C26	Manufacture of computer, electronic and optical products
C27	Manufacture of electrical equipment
C28	Manufacture of machinery and equipment n.e.c.
C29	Manufacture of motor vehicles, trailers, and semi-trailers
C30	Manufacture of other transport equipment
C31_C32	Manufacture of furniture; other manufacturing
C33	Repair and installation of machinery and equipment
D35	Electricity, gas, steam, and air conditioning supply
E36	Water collection, treatment, and supply
E37-E39	Sewerage; waste collection, treatment, and disposal activities; materials recovery; remediation activities and other waste management services
F	Construction
G45	Wholesale and retail trade and repair of motor vehicles and motorcycles
G46	Wholesale trade, except of motor vehicles and motorcycles
G47	Retail trade, except of motor vehicles and motorcycles
H49	Land transport and transport via pipelines
H50	Water transport
H51	Air transport
H52	Warehousing and support activities for transportation
H53	Postal and courier activities
I	Accommodation and food service activities
J58	Publishing activities

doi:10.6342/NTU202201643

Code	Sector
J59_J60	Motion picture, video and television programme production, sound recording and music publishing activities; programming and broadcasting activities
J61	Telecommunications
J62_J63	Computer programming, consultancy, and related activities; information service activities
K64	Financial service activities, except insurance and pension funding
K65	Insurance, reinsurance, and pension funding, except compulsory social security
K66	Activities auxiliary to financial services and insurance activities
L68	Real estate activities
M69_M70	Legal and accounting activities; activities of head offices; management consultancy activities
M71	Architectural and engineering activities; technical testing and analysis
M72	Scientific research and development
M73	Advertising and market research
M74_M75	Other professional, scientific, and technical activities; veterinary activities
N	Administrative and support service activities
O84	Public administration and defence; compulsory social security
P85	Education
Q	Human health and social work activities
R_S	Other service activities
T	Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use
U	Activities of extraterritorial organizations and bodies

Table 2. WIOD 2016 Release Countries and their Codes

Code	Region/Country
AUS	Australia
AUT	Austria
BEL	Belgium
BGR	Bulgaria
BRA	Brazil
CAN	Canada
CHE	Switzerland
CHN	China
CYP	Cyprus
CZE	Czech Republic
DEU	Germany
DNK	Denmark
ESP	Spain
EST	Estonia
FIN	Finland

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Code	Region/Country
FRA	France
GBR	Great Britain
GRC	Greece
HRV	Croatia
HUN	Hungary
IDN	Indonesia
IND	India
IRL	Ireland
ITA	Italy
JPN	Japan
KOR	South Korea
LTU	Lithuania
LUX	Luxembourg
LVA	Latvia
MEX	Mexico
MLT	Malta
NLD	Netherlands
NOR	Norway
POL	Poland
PRT	Portugal
ROU	Romania
RUS	Russia
SVK	Slovakia
SVN	Slovenia
SWE	Sweden
TUR	Turkey
TWN	Taiwan
USA	United States of America
ROW	Rest of the World

Updated Water Accounts

Due to the large amount of data, the updated water accounts for the WIOD 2016 release are uploaded and available online through the following link or through the QR code below: https://tinyurl.com/23a7bwhy

doi:10.6342/NTU202201643