Title:

"A Global Value Chain Analysis of Chinas Virtual Water Footprint through Agricultural Trade"

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By

Tariq Ali[*,1], Wei Xie [2], Anfeng Zhu [1]

[1] North China University of Technology, Beijing

[2] Peking University, Beijing

* agri45@gmail.com

Abstract:

The use of the global value chain (GVC) method has been gaining traction in recent research on resource use for production and trade. China has become one of the largest centers for forward- and backward-linkages for trade in inputs for agricultural and food products. Traditional methods of virtual water (VW) trade show the overestimation of China's use of foreign VW. Here, we use global value chain analysis based on the GTAP database to get the embodied trade of VW for China in the major agricultural sectors and agro-based industries. We find that China is a net importer of blue VW through its trade in primary and net exporter of blue VW through the processed agricultural commodities. It is a net importer of green VW through primary and processed agricultural commodities. The GVC method reveals that China is partially responsible for the imports of blue water, while the rest of the imports are caused by other countries through their imports of blue VW from China. We conclude that the sustainability of global water resources can be achieved through better estimates on VW trade and sharing the responsibility by the end-users.

1. Introduction

Due to the expanding population and increasing incomes, China's role in global food production, consumption, and trade has accelerated in the last few decades. Between 1970 and 2013, the per capita consumption of all food crops, dairy products, fruits and vegetables, and meat in China grew at 2.4%, 7%, 6.5%, and 4.8% annually, as compared to the global growth rates of 0.7%, 0.4%, 1.4%, and 1.1%, respectively. The high growth in food consumption in China was matched by the increase in production. Against 2.8% and 1.9% annual growth rates for the globe and Asia (excluding China), production of all primary food crops and livestock in China grew at 3.8% during 1970-2013. Even more impressively, fruits and vegetables, dairy, and meat production in China grew at 7.9%, 7.5%, and 6.0%, much faster than the global growth of 1.9%, 1.4%, and 2.1%, respectively. China also steadily increased food imports from the rest of the world, especially since the early 2000s. For example, China's imports of all primary food crops and livestock increased much faster (13.1%, annually) than the global imports (3.7%, annually), during 1970-2013 (FAO, 2019).

Along with several other factors, China's partial reliance on agricultural products on the foreign markets was driven by the increased stress on its domestic water and land resources. With the lowest availability of water and land resources in the world, China has been importing virtual water and land through its agricultural trade. Among the natural resources, water is perhaps the most critical one for agricultural production in China, mainly because of the already lowest per capita availability and the looming shortages due to future climate change. Although China hosts 20% of the world's population, it only has 5% of the global freshwater resources. Therefore, to fill the gap between water demand and supply, importing the water in virtual form is one of the most feasible options available to China.

As with trade in agricultural commodities in general, studies disagree on whether trade in the virtual resources is zero-sum-game for the importing and exporting countries. Some studies suggest the positive effects of trade in agriculture in the form of global and domestic savings of water resources. Several studies focusing on China have also concluded that China's agricultural trade saves virtual water for the country and the world as a whole. Still, other studies suggest significant adverse effects on exporting countries. Some of these studies have also focused on China's agricultural trade and found some environmental externalities for the exporting partners. We postulate that the disagreement is mainly the result of a partial analysis focusing only on either exporting or importing countries. By using the example of China's trade in virtual blue and green water, we contribute to the debate by incorporating the resource abundance/scarcity at both production and consumption points.

Given the looming stress and even scarcity of water in many regions of the world, our analysis can help generate several insights into the likely trade-offs between water savings in the importing country and risks to water resources (if any) at the production sites. The results of several studies suggest that agricultural exports from water-stressed regions can create further shortages at production sites, for example, growing depletion of groundwater at production sites, as discussed in Dalin (2016). On the one hand, our analysis of virtual water trade could indicate that water-stressed countries are ignoring their resource scarcity by continuing to over-draft their scarce water resources and exporting the water-rich products. On the other hand, it might help us understand that the importing countries might be contributing to saving more water through trade than they can if they produced these commodities locally.

Choosing the most appropriate method to trace the flow of virtual water is essential to draw meaningful conclusions about the sustainable use of water resources. The source of value of many products involves many countries or regions, but traditional trade statistics only record the total value of the product as the country or region that ultimately exports the product (Wang et al., 2015; Bart et al., 2015). The global production chain (global value chain) is characterized by the continuous refinement of the production processes of industrially manufactured products. The distribution of different production processes of one product in different countries has become a normal phenomenon. The production chain has been gradually elongated, the trade of intermediate goods has developed rapidly, and the intermediate products crossing multiple national borders are becoming increasingly common (Koopman et al., 2014; Marcel et al., 2014).

Previous studies using the input-output analysis to analyze trade embodied water, carbon, land, and pollutants are mostly based on one country's total trade volume. Peters (2008) compared the difference between the production-based NEI and consumption-based NEI, and constructed a consistent method of weighting production-based and consumption-based NEI using the country's total export. Chen et al. (2018) constructed a systems multi-regional input-output (MRIO) model to track agricultural land simultaneously, and freshwater use flows embodied in the global final goods export and pointed out that developed countries/regions and major large developing countries (China and India) are the overriding drivers of agricultural land and freshwater use globally. Zhao et al. (2015) assessed China's interprovincial virtual air pollution transfers embodied in the trade by using a consumption-based emission inventory based on the MRIO analysis framework and found that the massive amounts of emissions were embodied in the imports of eastern regions from northern and central areas. Zhang et al. (2017) assessed the impact of border-crossing frequency of intermediate goods on carbon emission along global value chains. They found that the aggregated average of border crossing frequencies of carbon footprints show an increasing tendency. Wang et al. (2019) pointed out the critical role of provincial domestic value chains in regional economic growth and carbon emissions of China, and the urgency of building a green value chain based on MRIO.

Although it is sufficient to use the traditional MRIO approach if we only want to figure out the number of domestic resources and other regions' resources consumed to meet the final use (Wang Z. et al., 2016), this analysis framework, however, often ignores a lot of details and results in a bias in terms of policy implications (Cadarso et al., 2018). Some analysts emphasized that researchers need to pay more attention to intermediate trade and trade structure at various levels for the applied studies of the economy and policy (Kanemoto et al. 2011; Jiang & Guan, 2017).

One of the significant contributions of this study is to use a more suitable approach – global value chain - to analyze the trade of blue virtual water in both importing and exporting countries to shed light on whether the trade in agricultural commodities contributes positively or negatively to water savings at both production and consumption points. Another contribution is that we use the water stress index to gauge whether the trade of virtual water exerts (alleviates) any pressure in the importing/exporting countries. In the literature, most of the studies either take the perspective of the exporting or importing country and study water without considering (the more scarce) blue water and (relatively less costly) green water. Basing our analysis on blue and green water allows us to draw a clearer picture of the role of virtual water trade in ameliorating (or adding) the water stress at both production and consumption points, thus providing in-depth perspectives for further policy debate. We also contribute to the literature by incorporating the relative aridity (dryness) of a country in its green virtual water trade.

The rest of the paper is structured as follows. Section 2 provides a brief background on production, consumption, and trade trends in China, sustainability implications of resource use in China and around the globe, and availability and stresses on water resources in China and the rest of the world. Section 3 describes the methods. Section 4 contains the results and discussion. Section 5 concludes the paper with some policy implications.

2. Background

2.1 China's production, consumption and trade of agricultural products in recent decades

China has been increasingly engaged in global food trade (Fig. 1). We see that since around 2008, China became a net importer of food from a traditional net-exporter. Besides, the gap between imports and exports of food commodities for China is growing wider ever since. In addition to food commodities, China has also been a net importer of large volumes of cotton for its textile sector (Fig. 1B). Since the early 1990s, China's net exports of textiles have been rising at a high rate (Fig. 2).

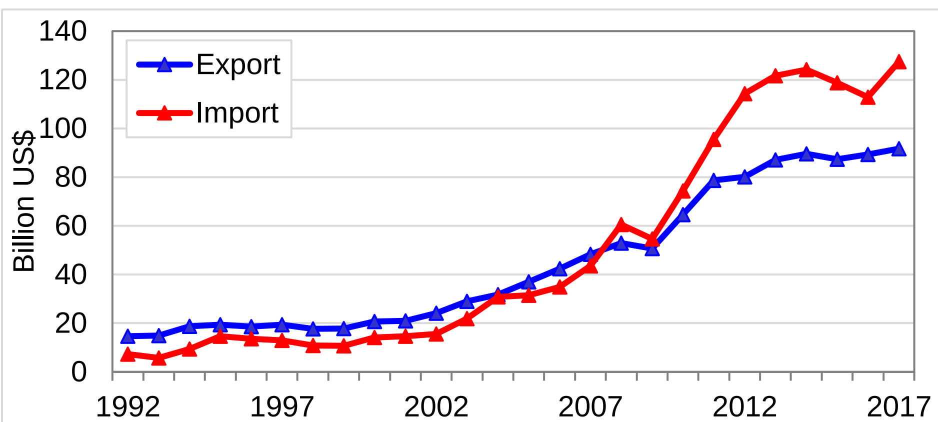

Fig. 1. Evolution of China's food trade during 1992-2017 (billion US$)

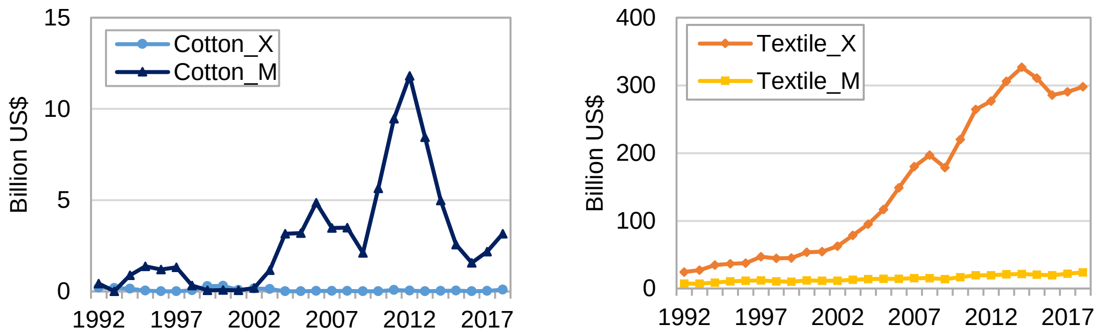

Fig. 2. Evolution of China's trade in cotton and textile (billion US$)

2.2 Sustainability of resource use in china and at the global level

China is currently facing an extreme water shortage. For example, the per capita water availability in China is only 30% of the worldwide average. The situation gets even worse when we look at the regional disparities in water availability inside China. The northern parts of China have just 3% of the global average of per capita water availability (Fig. 3).

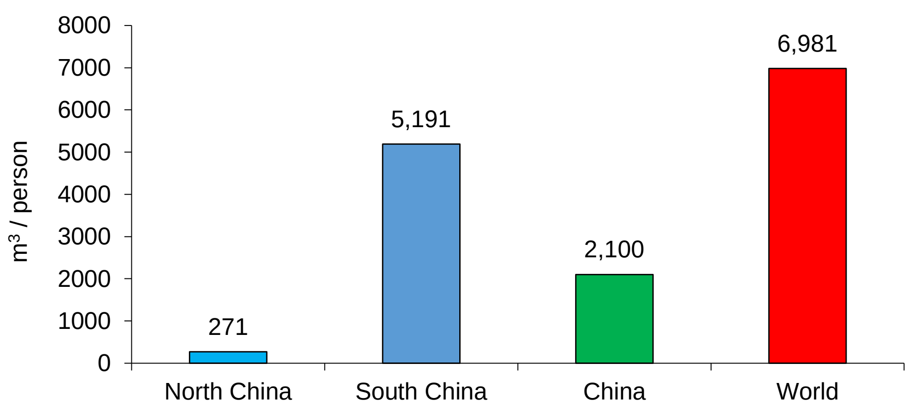

Fig. 3. Comparison of water availability between China and the world (m^3/ person)

The future of water resources looks even bleaker in China. Fig. 4 shows that in 2050, many of the regions in China will face more severe physical water scarcity than in 2010. The northeastern provinces, which are already under severe water stress, will face even higher water scarcity in the future. The looming increase in water scarcity, along with the effects of climate change, portrays a disturbing picture for the water resources in china.

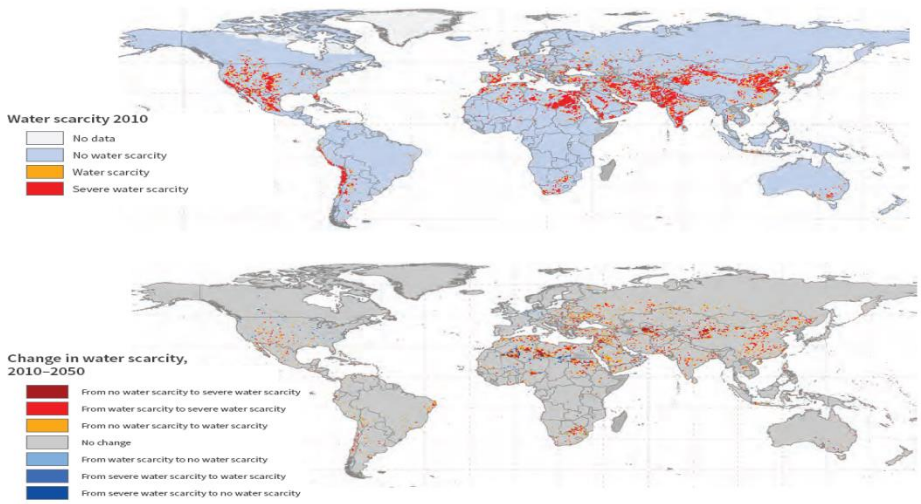

Fig. 4. Change in global water scarcity between 2010 and 2050 (Source: Burek et al., 2016, Fig. 4-39, p. 65).

2.3 Blue and green water availability in China and its trading partners

Water stress is another important indicator used in water-related literature, which shows the ratio of total annual freshwater withdrawals to hydrological availability in a country. In terms of the water stress, China's water stress index (WSI) is higher than most of its major trading partners (Table 1), indicating that if China imports VW from these countries, it would not only be able to release pressure on its domestic blue water resources but might also cause global savings of scarce blue water. Relative levels of precipitation in two regions/countries can also induce the movement of green VW embodied in merchandise trade. For the rainfall, we see that most of China's trading partners have higher precipitation rates than China (Table 1). This shows that the majority of these regions/countries are more humid and can serve as potential sources of green VW saving for China and the world.

Table 1. Water stress index and annual precipitation in China and its major trading partners

Country	WSI*	Precipitation (mm/year)**	Country	WSI*	Precipitation (mm/year)**
China	0.478	645	Kyrgyzstan	0.997	533
Argentina	0.352#	691	Korea	0.597	1274
Australia	0.402	534	Malaysia	0.434	2875
Belgium	0.715	847	Netherlands	0.306	778
Brazil	0.0659	1761	New Zealand	0.0226	1732
Canada	0.102	537	Philippines	0.396	2348
Chile	0.736	1522	Poland	0.070	600
France	0.181	867	South Africa	0.687	495
Germany	0.120	700	Spain	0.715	636
Indonesia	0.180	2702	Russia	0.111	460
India	0.967	1083	Thailand	0.534	1622

Italy	0.273	832	UAE	0.998	78
Japan	0.323	1668	UK	0.395	1220
Kazakhstan	0.616	250	USA	0.499	715

Source: * Pfister (2011), ** FAO Aquastat (2019), # green (orange) color indicates that these countries have lower (higher) water stress and higher (lower) precipitation than China.

3. Methods and Data

For the embodiment analysis of blue water use in the global economic system, we constructed a systems MRIO model integrating both direct resource use and monetary flows.

3.1 Measuring embodied water use by GVC decomposition method

In recent years, the international trade of embodied water use has been a subject of substantial interest in the academic area. However, most MRIO-based decomposition measures of trade in embodied water use in the literature often focus on the global and country aggregate level, which tends to ignore many crucial details (Meng B. et al., 2018). We can use this traditional approach if we only want to figure out the number of domestic resources and foreign resources consumed to meet the final use (Wang Z. et al., 2016). It is, however, often necessary to measure the value and structure of domestic value and other parts of exports at various levels for many applied studies of the economy and policy, mainly because of the observation that intermediate trade accounts for a growing proportion of global trade nowadays (Kanemoto, et al. 2011; Jiang & Guan, 2017; Zhang et al., 2017; Cadarso et al.,2018;). In the latter case, we need a decomposition of intermediate product trade between different countries based on backward industrial linkage.

This section explains the methodology based on a world composed of G countries and N sectors. These countries are connected through the inter-regional trade of intermediate and final products, and each country’s outputs are used to satisfy intermediate or final consumption.

Eq. (1)

$$\begin{bmatrix} X^1 \\ X^2 \\ \vdots \\ X^g \end{bmatrix} = \begin{bmatrix} A^{11} & A^{12} & \cdots & A^{1g} \\ A^{21} & A^{22} & \cdots & A^{2g} \\ \vdots & \vdots & \ddots & \vdots \\ A^{g1} & A^{g2} & \cdots & A^{gg} \end{bmatrix} \begin{bmatrix} X^1 \\ X^2 \\ \vdots \\ X^g \end{bmatrix} + \begin{bmatrix} \sum_r^G Y^{1r} \\ \sum_r^G Y^{2r} \\ \vdots \\ \sum_r^G Y^{gr} \end{bmatrix}$$

where X^s represents the gross output of country s(s=1, ⋯,g), Y^{sr} represents the final demand of country r(r=1, ⋯,g) for products from country s, A^{sr} is the input coefficient matrix that represents the intermediate use in country r of goods produced in country s. The elements of the input coefficient matrix satisfy $a_{ij}^{sr} = z_{ij}^{sr} / x_j^r$, where z_{ij}^{sr} (i,j=1, ⋯,n) represents the transfer from sector i of country s to sector j of country r. The intermediate input matrix from country s to country r is represented by $z^{sr} = A^{sr} / X^r$. Eq. (1) can be rearranged as

Eq. (2)

$$\begin{bmatrix} X^1 \\ X^2 \\ \vdots \\ X^g \end{bmatrix} = \begin{bmatrix} I-A^{11} & -A^{12} & \cdots & -A^{1g} \\ -A^{21} & I-A^{22} & \cdots & -A^{2g} \\ \vdots & \vdots & \ddots & \vdots \\ -A^{g1} & -A^{g2} & \cdots & I-A^{gg} \end{bmatrix}^{-1} \begin{bmatrix} \sum_r^G Y^{1r} \\ \sum_r^G Y^{2r} \\ \vdots \\ \sum_r^G Y^{gr} \end{bmatrix} = \begin{bmatrix} B^{11} & B^{12} & \cdots & B^{1g} \\ B^{21} & B^{22} & \cdots & B^{2g} \\ \vdots & \vdots & \ddots & \vdots \\ B^{g1} & B^{g2} & \cdots & B^{gg} \end{bmatrix}^{-1} \begin{bmatrix} \sum_r^G Y^{1r} \\ \sum_r^G Y^{2r} \\ \vdots \\ \sum_r^G Y^{gr} \end{bmatrix}$$

where B^{sr}, the Leontief inverse, represents the quantity of the gross output of country s for a one-unit increase in the final demand of country r. From Eq. (2), the gross output of country r is as follows:

Eq. (3)

$$X^r = \sum_t^G B^{rt} \sum_u^G Y^{tu}$$

The intermediate input of country r from country s is $Z^{sr} = A^{sr} X^r$ The exports from country s to country r are $T^{sr} = Y^{sr} + A^{sr} X^r$.

Eq. (4)

$$\begin{aligned} T^{sr} &= Y^{sr} + A^{sr} X^r \\ &= \underbrace{Y^{sr} + A^{sr} B^{rr} Y^{rr} + A^{sr} B^{rs} Y^{sr} + A^{sr} \sum_{t \neq s,r}^G B^{rt} Y^{tr}}_{T\_f^r} + \underbrace{A^{sr} B^{rr} Y^{rs} + A^{sr} B^{rs} Y^{ss} + A^{sr} \sum_{t \neq s,r}^G B^{rt} Y^{ts}}_{T\_f^s} \\ &\quad \underbrace{+ A^{sr} B^{rr} \sum_{t \neq s,r}^G Y^{rt} + A^{sr} B^{rs} \sum_{t \neq s,r}^G Y^{st} + A^{sr} \sum_{t \neq s,r}^G B^{rt} \sum_{u \neq s,r}^G Y^{tu}}_{T\_f^{other}} \end{aligned}$$

Based on the balance of gross output $X^s = A^{ss} X^s + Y^{ss} + \sum_{s \neq r}^M T^{sr}$, we can decompose the gross output generated from each industry/country into different components:

Eq. (5)

$$X^s = L^{ss} Y^{ss} + L^{ss} \sum_{s \neq r}^G T\_f^r + L^{ss} \sum_{s \neq r}^G T\_f^s + L^{ss} \sum_{s \neq r}^G T\_f^{other}$$

where $L_{rr} = (I - A_{rr})^{-1}$ is the domestic Leontief inverse matrix of country r. T_f^r represents the water finally consumed by country r. T_f^s represents the water finally consumed by the country s. T_f^{other} represents the water finally consumed by other countries.

We define the water intensity of the agricultural sector p of the country s as $f^{ps} = w^{ps} / x^{ps}$, where w^{ps} represents the water consumption of agricultural sector p of country s. $F_{ps}=(f_{p_1 s}, f_{p_2 s}, \cdots, f_{p_7 s}, f_{ps}, 0, \cdots, 0)$ is a diagonal matrix composed of f_{ps}. The water consumption of country s is

Eq. (6)

$$W^{ps} = F^{ps}X^{s} = F^{ps}L^{ss}Y^{ss} + F^{ps}L^{ss}\sum_{s \neq r}^{G} T\_f^{r} + F^{ps}L^{ss}\sum_{s \neq r}^{G} T\_f^{s} + F^{ps}L^{ss}\sum_{s \neq r}^{G} T\_f^{other}$$

W^{ps} is the water consumed in the country's agricultural sectors, we can divide it into two parts as the form it consumed. The first part is the water embodied in agricultural products which it consumed as final products. Another part is the water embodied in the productions which consumed as intermediate goods. So, the water embodied in intermediate goods is

$$W^{nps} = (W^{ps} - F^{ps}diag(A^{ss}X^{s}) - Y^{ss} - \sum_{r \neq s}^{G} T^{sr})\ C^{ss})'$$

$C^{ss} = (Z^{ss} - diag(Z^{ss})\ ) * \ (X^{s})^{-1}$, it presents the ratio of the agricultural products consumed in Non-agricultural sectors, and the water consumption intensity of the np sector in S country is $f^{nps} = T_{NPK}{}^{nps} / (Y^{ss} + T^{sr})$. Therefore, the water consumption intensity of all sectors in the country S is:

$$F^{s} = (f^{p_1 s}, f^{p_2 s}, \cdots, f^{p_7 s}, f^{np_8 s}, f^{np_9 s}, \cdots, f^{np_{17} s})'$$

F^{s} represents the increase in domestic water caused by an increase of one unit in the country s exports. So, the domestic water embodied in the exports from country s to country r is

Eq. (7)

$$WEX^{sr} = F^{s}T^{sr}\_f^{r} + F^{s}T^{sr}\_f^{s} + F^{s}T^{sr}\_f^{other}$$

Based on Eq (7), The gross domestic water of country s exports to country r is decomposed into three paths. Path 1 means that water is implied in products exported from country s to country r, which are directly consumed or used as intermediate products for production in other sectors by country r. Path 2 means that water is implied in the commodities exported from country s to country r, which are used by country r to produce other commodities and then returned back and finally consumed by country s. Path 3 means that water is implied in the products exported from country s to country r, which are used by country r to produce other commodities and then re-export to other countries (not country s or country r) and finally consumed by other countries. Each part of Eq (7) represents the domestic water embodied in the products produced in Country s. This method will result in the double-counting problem because a country's water embodied in intermediate exports can also be observed as the indirect emissions embodied in another country's exports of final products. To avoid the double-counting problem, this present paper only focuses on domestic emissions that are induced by exports only through domestic economic linkage.

3.2 Data

We use three types of data for the GVC analysis: monetary MRIO table, agricultural freshwater (blue water) use, and agricultural use of rainfall (green water). Monetary MRIO table data set is obtained from GTAP, which is based on the GTAP database version 9 (Aguiar et al., 2016). For the agricultural use of and agricultural freshwater (blue water) and rainfall (green water), we have used various sources, as described below.

3.2.1 Monitory MRIO table from GTAP

In this study, we use the latest GTAP database version 9 (with the base year of 2011). The standard GTAP database contains 140 countries/regions and 57 sectors. We aggregate the GTAP database into 18 sectors while ensuring that all the primary and processed agricultural sectors are present in the most disaggregated form. At the same time, we aggregate the GTAP regions into 12 regions while keeping the detailed representation of all the main trading partners of China.

3.2.2 Agricultural freshwater (blue water) use

We used the following method to estimate the blue VW (f = w/x) for all the sectors and regions corresponding to GTAP database V9 (2011 base year).

1) Crop water requirement (Siebert and Döll, 2010): This data set represents worldwide information on water requirements for irrigation for 29 crop categories at a 5-minute spatial resolution. This database represents water requirements for 2000.

2) Irrigation Water Requirement (IWR) by country in 2011: This data set is obtained from the FAO's global water information system (AQUASTAT).

3.2.3 Agricultural use of rainfall (green water)

To obtain the rainwater (green water) use by crops, we rely on the blue water use in the previous subsection and ratios between the blue and green of the water used for crop production. We obtain these ratios based on the blue and green water use per unit of the crop, as described in Hanasaki (2016). We then get the green water use through the following equation:

$$GW_{i,r} = \frac{G}{B}Ratio_{i,r} \times BW_{i,r} \qquad (12)$$

Where $GW_{i,r}$ is the amount of green water embodied in the production of per unit of a crop i in country/region r; $\frac{G}{B}Ratio_{i,r}$ is the ratio of green to blue water and $BW_{i,r}$ is the blue water used in per unit production of crop i and country/region r.

4. Empirical results

Due to increasing income and expanding population, China's role in global production, consumption, and trade of agricultural commodities has grown tremendously. China has also emerged as a hub for the processing of raw agricultural products into value-added products. These commodities use both domestic and foreign resources, including water resources, in their production process. In the following, we present the main results of our global value chain analysis of China's trade in blue and green water resources through the country's trade in primary and processed agricultural commodities in the year 2011.

4.1 Net VW imports by China through different commodities

China is a net importer of blue VW through the primary agricultural commodities (13.3 billion m^3, the sum of all the columns in Fig. 5A) but a net exporter of blue VW through the processed agricultural commodities (21.8 billion m^3, the sum of all the columns in Fig. 5B). The result is a net-export of 8.48 billion m^3 of blue VW from China. The highest net import of blue VW is through the import of cotton (13.6 billion m^3), oilseeds (3.3 billion m^3, which is mostly soybean), and sugar (0.6 billion m^3) crops.

Sectors like other chicken + pork are the main primary agricultural commodities responsible for the net-export of blue VW, although in relatively small quantities (1.2 billion m^3). For the processed agricultural commodities, the net exports are dominated by textile (processed cotton) and leather (12.0 billion m^3) and followed by processed food sectors (5.5 billion m^3).

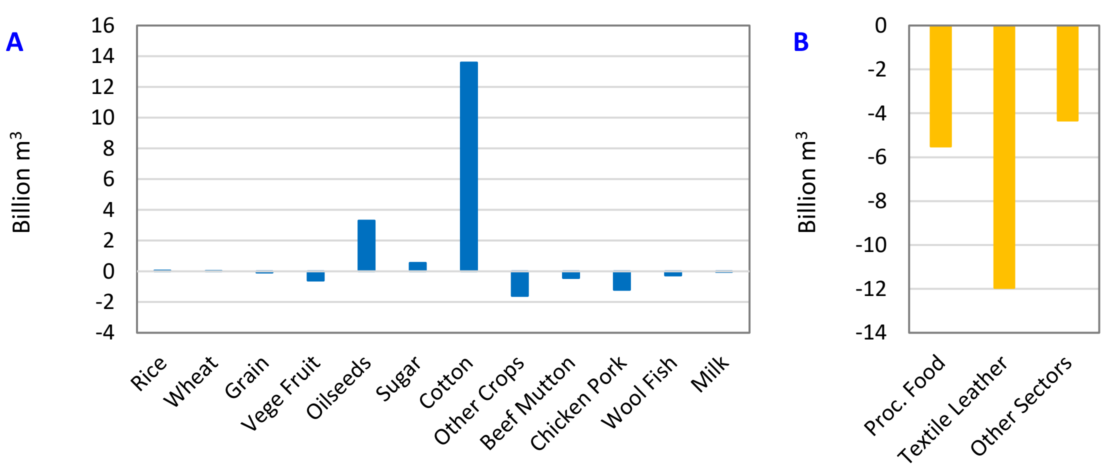

Fig. 5. Net imports of blue VW embodied in (A) primary and (B) processed agricultural commodities (billion m^3).

For the green VW, China is a net importer of the VW through most of the agricultural commodities, with a total net-import 51.3 billion m^3 (Fig. 6). In terms of the primary agricultural commodities, oilseeds (72.0 billion m^3) and cotton (14.1 billion m^3) dominate the net-import of green VW (Fig. 6A). Among the processed agricultural commodities, textile and leather sectors (29.7 billion m^3) shows the highest net export of green VW by China (Fig. 6B).

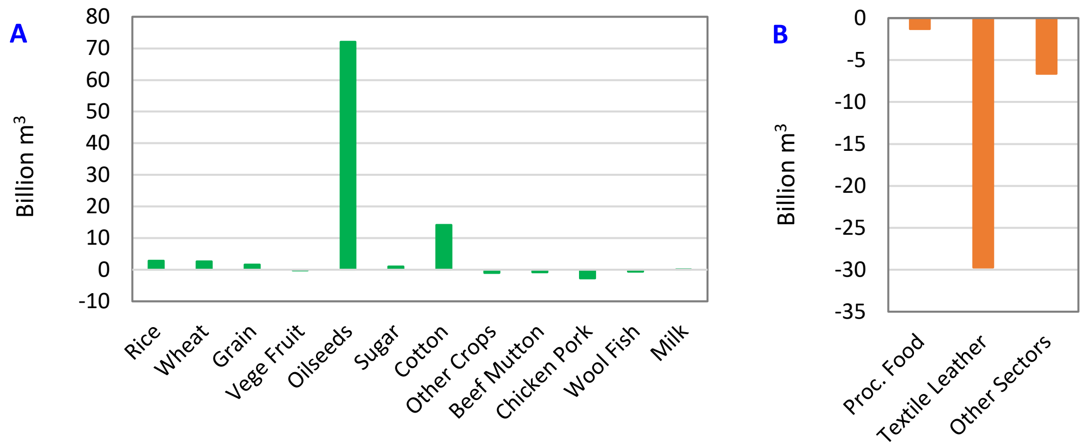

Fig. 6. Net imports of green VW embodied in (A) primary and (B) processed agricultural commodities (billion m^3).

One of the advantages of using the GVC approach is that we can analyze whether the virtual water is consumed in the importing country or it is re-exported to other countries, which we present in the following sub-section.

4.2 Net VW imports by China through different pathways

Not all the VW entering China is consumed within China by its consumers, rather big chunks of VW imported by China is re-exported via the primary and processed agricultural commodities to the source and third countries (Figs. 7). For cotton, the biggest net-importing commodity of blue VW for China, we see that about 56% (7.6 billion m^3) of blue VW imported by China is used for domestic consumption, while the rest, 6.0 billion m^3, is re-exported to the outside world via different trade pathways (Fig. 7A). For oilseeds (which mainly consists of soybean) and rice, the ratio of domestic use of imported blue VW by China are bit higher (88% and 96), showing that most of the blue VW imported through oilseeds and rice is consumed within China, and the rest (12% and 4%) is re-exported to the source or the third countries in the form of intermediate or final goods.

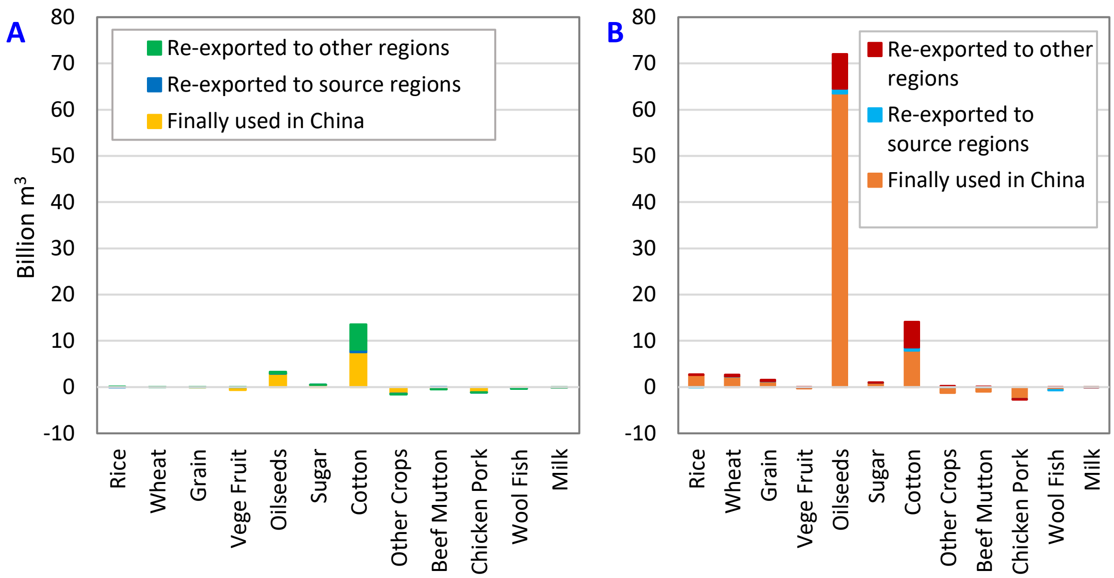

Fig. 7. Shares of different pathways in net-imports of (A) blue VW and (B) green VW through major primary agricultural trading commodities (billion m^3)

For green VW, we see that China uses a large portion of the imported green VW (63.5 billion m^3) through the imports of oilseeds for its domestic use, while the rest (8.6 billion m^3) is re-exported to other countries (Fig. 7B). We observe similarly large ratios of green VW used by the consumers in China for cotton and rice.

4.3 Sources and destinations of China's net VW imports

Now we discuss the origin and destination countries/regions of trade in blue and green VW for Chin. Fig. 8 shows that China imports about 97% of its blue VW for domestic use through oilseeds (mostly consisting of soybean) from South and North America. Imports of blue VW through cotton is mainly concentrated in South and Central Asia (72 %), followed by North America (23%). Fig. 8 also shows the final use of the net-imports of blue VW by China. China exports large volumes of blue VW's that it accounts for its net imports blue VW through cotton trade.

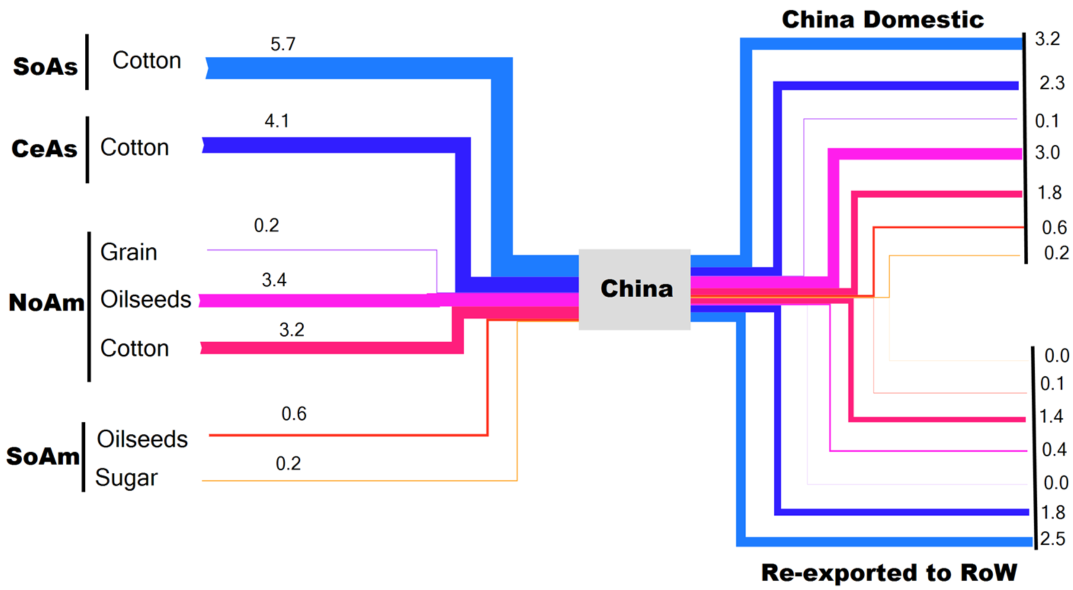

Fig. 8. Sources and destinations of China's blue VW net-imports through major primary agricultural traded commodities.

The source countries for green VW trade by China are almost the same as for blue VW; however, there are considerable differences in quantities. We can see in Fig. 9 that about 55% of green VW embodied in China's imports of oilseeds for its domestic use comes from South America and 44% from North America. With a total share of 71%, the import of green VW through cotton trade by China is dominated by two regions, i.e., South Asia and North America. Large quantities of green VW net-imports by China through trade in oilseeds and cotton is either exported to the source or the third countries.

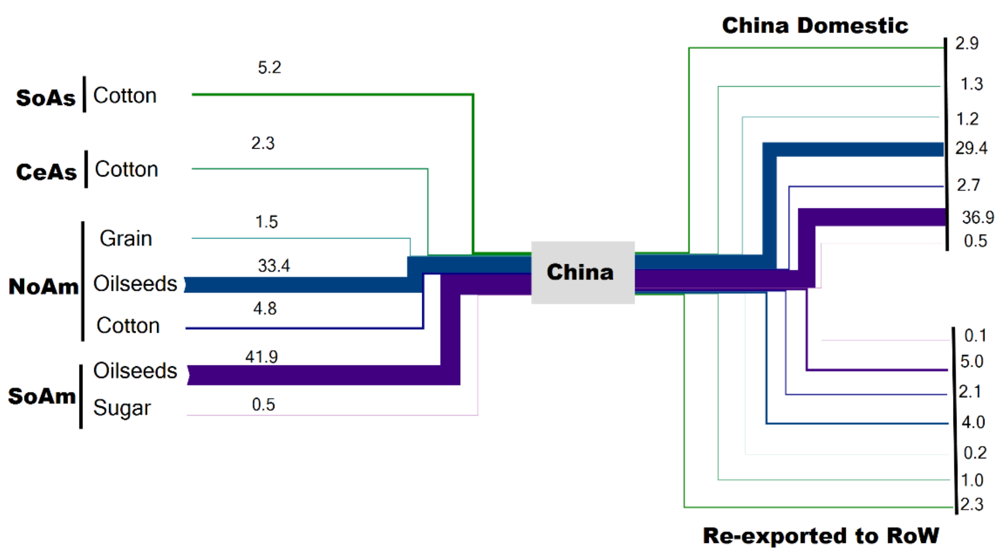

Fig. 9. Sources and destinations of China's green VW net-imports through major primary agricultural traded commodities.

5. Conclusions

Sustainable use of natural resources, including water, is one of the biggest challenges facing humanity. The interaction between domestic and global solutions to resource sustainability has the potential to furnish novel policy measures.

We use the GVC method to present more accurate measures of virtual water trade through China's trade in primary and secondary agricultural commodities. We also isolate the shares of China's imports of VW that China uses domestically and re-exports to the outside world. We find that China's is a net-importer of blue and green VW through its trade in primary agricultural commodities. However, for the processed agricultural commodities, although China is still a net-importer of green VW, a net-exporter of (the more scarce) blue VW. We also discover that large shares of VW imported by China are not finally used within its borders, instead are exported to the outside world.

There are, however, a couple of implications that need further attention. Devising policies for sustainable resource use at national and global levels require accurate estimate methods. Without reliable estimates, the policy guidelines based on unreliable results might cost more than they benefit. Another implication is that when accounting for global resource depletion, we need to pay attention to the end-users of these resources rather than focusing on the initial importers of the resources.

One shortcoming of this study is that we use a point analysis for the year 2011 only. Future studies covering more recent data and maybe a time series analysis would give a clearer picture of the evolution of VW trade through China's trade in agricultural commodities. Moreover, better estimates of green VW and the improved methods to incorporate the trade of VW through processed agricultural commodities are also expected to improve the analysis, which should be included in future studies.

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