Driving factors of agricultural virtual water trade between China and the Belt and Road countries

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Abstract: China proposed the Belt and Road Initiative (BRI), an unprecedented development strategy in terms of scope and scale, to increase the connectivity with the rest of the world by infrastructure development and trade activities. Recently, more attention has been directed to the environmental implications of the international trade activities under this initiative, which contributes to the development of a green, i.e. environmentally friendly partnership. This study examines the evolution of virtual water trade in relation to agricultural products between China and BRI countries during 2000-2016. The Logarithmic Mean Divisia Index (LMDI) method is adopted for uncovering the driving factors underlying the trade imbalance, as well as the major virtual water exports. Results reveal that China has experienced the shift from a net virtual water exporter to a net importer. At the regional level, Southeastern Asia and Southern Asia are the major net virtual water exporters to China, and Eastern Asia is the major importer. For the selected export countries, an increase in proportion of trade in relation to domestic production significantly contributes to their virtual water export, while water intensity could decrease virtual water export for most export countries. As for the driving forces behind the imbalance of virtual water trade, trade structure was an obvious positive effect, while the effects of water intensity, product structure and trade scale shifted in favor of virtual water outflows from BRI countries to China in 2008. Massive global water loss has incurred, indicating the inefficiency of this partnership in relation to freshwater. A closer trade relationship is established between China and BRI countries, and relevant environment implications are identified. Policy implications are proposed in terms of trade structure, relationship of trade and domestic production, and international cooperation. This study provides valuable insights into the equity and sustainability of historic trade activities with respect to freshwater resources.

Key words: virtual water trade; LMDI decomposition; water management; Belt and Road Initiative

1. Introduction

China's Belt and Road Initiative (BRI), which was first proposed in 2013, is an effort to promote connectivity and cooperation among countries along the Silk Road Economic Belt and the 21st-Century Maritime Silk Road. As an open arrangement that welcomes all countries to participate, there is no official list of "BRI countries". As of July 2018, 71 countries had become involved in this initiative, with a combined population of approximately 3.5 billion and investments worth trillions of dollars.[1] According to the official statistics,[1] during the past five years (2013-2017), the development of free trade zones as well as increased investment from China to the BRI countries improved infrastructure and financial services and helped to bring down the trade barriers between China and countries along BRI. Under such circumstances, the growth rate of China' total foreign trade was 7.56% in 2013 and 7.45% in 2017. In contrast, the growth rate of China' trade with the BRI countries was 7.86% in 2013 and 13.45% in 2017. In 2017, the trades of BRI countries and China accounted for 27.8% and 12.1% of total global trade, respectively. Moreover, the trade between China and BRI countries accounted for 36.2% of China's total foreign trade. In 2017, the Chinese government released a national document to prioritize a "Green Belt and Road" in response to the growing environmental concerns raised by BRI countries.[2] Due to its unprecedented scope and scale as a development strategy, former BRI studies mostly focused on the geopolitical and economic implications of this Initiative.[3] The promotion of a green BRI was done to minimize the associated environmental harms. Embodied flows in relation to carbon, water, energy, land, pollution, etc., have been analyzed for various trade partnerships.[4] However, few academic endeavors have been made on the environmental dimension of the BRI, barring some studies on carbon emissions[5, 6] and the historical virtual water flows[7] between China and countries along the Belt and Road.

Given the significant variation of natural resource endowment among BRI countries (e.g. total renewable water resources per capita in 2014 ranges from 5 m^3 in Kuwait to 100,671 m^3 in Bhutan)[8] the question arises as to whether the burgeoning trade activities under the initiative did, or are likely to, alleviate or exacerbate water scarcity at a national or international level. In particular, accounting for 80% of total freshwater consumption, agriculture has already become the focus of the endeavor to reduce water use while ensuring national food security.[9] This study attempts to undertake a comprehensive analysis of the embodied water flows and the underlying driving forces in relation to agricultural products between China and BRI countries.

Virtual water (i.e. embodied water) refers to the total freshwater consumption throughout the production process for a certain product.[10] A comprehensive analysis of virtual water flows reveals water resource transfers through the distribution of traded goods and services across national borders. In 2002, Hoekstra introduced the water footprint concept based on virtual water theory,[11] and expanded the research boundaries of traditional water management from the consumption of surface water or groundwater ("blue water") to rainwater ("green water") and polluted water ("gray water").[10] Water footprint assessment has been performed at levels ranging from global, national, river basins, to cities.[10] The major driving forces underlying the evolution of water footprints, such as technological change and economic expansion, have been identified.[12-14] As for virtual water trade, a growing body of research was carried out to address water use, scarcity, and pollution issues at national[15-17] or global level.[18-20] Hoekstra and Mekonnen[21] presented a comprehensive report on international virtual water trade that identified countries highly dependent or exerting significant impacts on external water resources. Qu et al.[22] further pointed out that nations may suffer from economic losses due to water scarcity both from local sources and upstream suppliers as water scarcity risk can be transmitted through the globalized supply chains. Due to the large share of water consumption in crop and livestock products, the network structure and determinants of global virtual water flows embedded in food trade have been extensively investigated.[9,23,24] For instance, Tamea et al.[23] identified population, GDP, and geographical distance between countries to be the major drivers of global virtual water trade, while the contribution of agricultural production of exporting countries is not negligible. Fracasso[24] found national water endowments and level of pressure on water resources tend to constrain overexploitation for virtual water exporters, though conclusions obtained at a global scale may be at odds with those studies taking on a smaller subsample of countries, which in this study is the trade partnership between China and BRI countries. It is worth point out uncertainties related to water stress indicators and the wider issue of assessing socioeconomic implications of water stress;[25] neither of which are explicitly addressed in our paper.

This study aims to fill the research gaps in the field of green BRI trade by: (1) measuring the impacts of domestic production of agricultural products and associated water scarcity on China’s exports; (2) uncovering the driving factors for trade imbalance in terms of agricultural virtual water; and (3) analyzing the impact of virtual water trade on global water savings. It improves former efforts by performing a comprehensive analysis of the trade network under the BRI framework from the perspective of sustainable freshwater management. The main objectives include the following: (1) to examine the trade network under the Belt and Road Initiative; (2) to identify the environmental implications, including resource savings and redistribution at a global level or water scarcity and pollution at a regional level; and (3) to explore the underlying driving forces so that the potential solutions can be found. The Logarithmic Mean Divisia Index (LMDI) method is employed to examine the driving forces, which has been widely adopted in decomposition analyses uncovering impacting factors of embedded resources in trade.[26-28]

This research proposes a decomposition method for virtual water trade, specifically export, which incorporates factors including trade pattern, domestic economics, water scarcity, and population. In the context of globalization and improved regional cooperation, more cross-border trade may lead to improved growth while creating negative environmental implications. This study will provide insights into the equity and sustainability of historic trade activities and yield relevant policy implications for the development of a "Green Belt and Road".

The remainder of this paper is organized as below. Section 2 introduces the background of BRI and the methods about virtual water and driving force analysis. Section 3 provides the results of a detailed analysis of virtual water trade between China and BRI countries, and Section 4 discusses policy implications based on the aforementioned results.

2. METHODS AND DATA

2.1 International Virtual Water Flows. Virtual water flows are calculated by multiplying the volume of trade (per trade commodity) by the respective virtual water content (average water footprint per ton of product) in the exporting nation.[21] The total virtual water flow is calculated by adding up the virtual water flows of all agricultural products (including green, blue, and gray water), as shown in eq 1:

$$VWF_{i\rightarrow j} = \sum_k VWF_{i\rightarrow j,k} = \sum_k \sum_c TV_{i\rightarrow j,k} \times VWC_{i,k,c} \quad (1)$$

where $VWF_{i\rightarrow j}$ represents the total virtual water flow from exporting nation i to importing nation j; $VWF_{i\rightarrow j,k}$ and $TV_{i\rightarrow j,k}$ represent the virtual water flow and trade volume of product k from nation i to nation j, respectively; $VWC_{i,k,c}$ represents the virtual water content for component c (i.e. green, blue, and gray water) of product k from nation i.

2.2 Virtual Water Export Decomposition. Although most of the BRI countries have been importing virtual water from China, some of them have remained as the major exporters to China over the years. To explore the driving factors, this study selected seven nations (including Malaysia, India, Turkey, Hungary, Lithuania, Ethiopia and New Zealand) as the representatives of major net virtual water exporter to China in each region. In an attempt to evaluate the impacts of virtual water export on national water resources, this study proposed a decomposition approach based on LMDI method that links virtual water export to local water scarcity through domestic production, as shown in eq 2 and eq 3:

$$VWF = \sum_i \frac{VWF_i}{V_i}\frac{V_i}{V}\frac{V}{GDP}\frac{GDP}{WW}\frac{WW}{WA}\frac{WA}{P}P \quad (2)$$

$$\Delta VWF_{total} = \Delta VWF_{WI} + \Delta VWF_{PS} + \Delta VWF_{ES} + \Delta VWF_{WP} + \Delta VWF_{WV} + \Delta VWF_{WS} + \Delta VWF_{P} \quad (3)$$

where VWF_i represents the total export virtual water flow of the product i; V_i represents the export monetary trade volume, and subscripts i refers to the product; V represents the total export monetary trade volume of the country; *GDP* refers to the added value of agriculture sector; *WW* refers to the agricultural water withdrawal; *WA* refers to the total renewable water resources; *P* refers to population. ΔVWF_{WI} refers to water intensity effect; ΔVWF_{PS} refers to product structure effect; ΔVWF_{ES} refers to economic structure effect, which is the proportion of trade value in domestic production in agricultural sector; ΔVWF_{WP} refers to water productivity effect, which is the agricultural added value per unit of agricultural water withdrawal; ΔVWF_{WV} refers to the water vulnerability effect, which is the proportion of agricultural water withdrawal in total water availability (renewable water resources); ΔVWF_{WS} refers to water scarcity effect, which is per capita renewable water resources; and ΔVWF_{P} refers to population effect. Thus, the driving factors can be described as follows:

$$\Delta \mathrm{VWF_{total}} = \Delta \mathrm{VWF_t} - \Delta \mathrm{VWF_0} = \Delta \mathrm{VWF_{WI}} + \Delta \mathrm{VWF_{PS}} + \Delta \mathrm{VWF_{ES}} + \Delta \mathrm{VWF_{WP}} + \Delta \mathrm{VWF_{WV}} + \Delta \mathrm{VWF_{WS}} + \Delta \mathrm{VWF_{P}} \quad (4)$$

$$\Delta \mathrm{VWF_X} = \sum_{\mathrm{i}} \frac{\mathrm{VWF_{i,t}} - \mathrm{VWF_{i,0}}}{\ln \mathrm{VWF_{i,t}} - \ln \mathrm{VWF_{i,0}}} \ln \frac{\mathrm{X_{i,t}}}{\mathrm{X_{i,0}}} \quad (5)$$

where *X* refers to the seven effects mentioned above, and the subscripts *t* and *0* refer to the final year and benchmark year, respectively.

2.3 Trade Imbalance Decomposition. To examine the driving factors underlying the net virtual water flows, this study employs an approach introduced by Chen et al.[28] to decompose the differences between the virtual water export and import, as shown in eq 6 and eq 7:

$$VWF = \sum_i \sum_j \frac{VWF_{ij}}{V_{ij}} \frac{V_{ij}}{V_j} \frac{V_j}{V} V = \sum_i \sum_j WI_{ij} \times PS_{ij} \times TSt_j \times TSc \quad (6)$$

$$\Delta VWF_{total} = \Delta VWF_{WI} + \Delta VWF_{PS} + \Delta VWF_{TSt} + \Delta VWF_{TSc} \quad (7)$$

where *V* represents the monetary trade volume, and subscripts *i* and *j* refer to the product and the country, respectively. WI_{ij} refers to water intensity, which is the virtual water flow per monetary unit of trade volume of product *i* with country j. PS_{ij} refers to product structure, which is the share of trade volume of product *i* in the total import or export with country j. TSt_j refers to trade structure, which is the share of trade volume of country *j* in the corresponding total import or export of BRI countries. TSc refers to trade scale, which is the monetary value of total import or export of BRI countries. Correspondingly, ΔVWF_{WI}, ΔVWF_{PS}, ΔVWF_{TSt}, ΔVWF_{TSc} refer to water intensity effect, product structure effect, trade structure effect, and trade scale effect. Thus, the driving factors for the net virtual water export can be described as eq 8:

$$\Delta VWF_{total} = \Delta VWF_{ex} - \Delta VWF_{im} = \Delta VWF_{WI} + \Delta VWF_{PS} + \Delta VWF_{TSt} + \Delta \mathrm{VWF_{TSc}} \quad (8)$$

$$\Delta VWF_X = \sum_i \sum_j \frac{VWF_{ij,ex} - VWF_{ij,im}}{\ln VWF_{ij,ex} - \ln VWF_{ij,im}} \ln \frac{X_{ij,ex}}{X_{ij,im}} \quad (9)$$

where *X* refers to the four effects mentioned above, and the subscripts *ex* and *im* represent China's export and import, respectively.

2.4 Global Water Savings From Trade. Global water saving (WS) represents the amount of water saved (if $WS > 0$) or lost (if $WS < 0$) at the "global" level (encompassing all trade partners) from trade compared to a hypothetical scenario of autarky of every trade partner.[29] It is calculated by multiplying the volume of trade by the difference of virtual water contents between the importing and the exporting nations, as shown in eq 10:

$$WS_{i\to j} = \sum_k WS_{i\to j,k} = \sum_k \sum_c TV_{i\to j,k} \times (VWC_{j,k,c} - VWC_{i,k,c}) \quad (10)$$

where $WS_{i\to j}$ represents the total water saving due to export from country i to country j; and the subscript i, j, k, and c represent exporting country i, importing country j, product k, and virtual water component c, respectively.

2.5 Data Sources and Treatment. 2.5.1. *Countries engaged in the Belt and Road Initiative*. The Belt and Road Initiative is geographically structured between China and other countries, including but not limited to Eurasian. Table 1 is an alphabetical list of the 71 countries involved in the initiative to date,[30] and the geographic region they each belong according to the M49 Standard.[31]

Table 1. Countries engaged in the Belt and Road Initiative

Geographic region	Country
Southeastern Asia	Brunei Darussalam, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand, Timor-Leste, Vietnam
Southern Asia	Afghanistan, Bangladesh, Bhutan, India, Iran, Maldives, Nepal, Pakistan, Sri Lanka
Central Asia	Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan
Western Asia	Armenia, Azerbaijan, Bahrain, Georgia, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, State of Palestine, Syria, Turkey, United Arab Emirates, Yemen
Eastern Asia	Republic of Korea, Mongolia
Oceania	New Zealand
Eastern Europe	Belarus, Bulgaria, Czech Republic, Hungary, Moldova, Poland, Romania, Russian Federation, Slovakia, Ukraine
Northern Europe	Estonia, Latvia, Lithuania
Southern Europe	Albania, Bosnia and Herzegovina, Croatia, Macedonia, Serbia and Montenegro, Slovenia
Africa	Egypt, Ethiopia, Madagascar, Morocco, South Africa
Americas	Panama

2.5.2.*Agricultural Trade and Virtual Water Content*. The agricultural trade data between China and BRI countries were obtained from China's customs statistics yearbooks.[32-34] The virtual water contents of agricultural products were obtained from WaterStat.[35-37] For the compatibility of agricultural products from varied sources, some revisions were made to reconcile the HS code adopted in custom data and FAO code adopted in the virtual water report. This study examines a total of 21 product categories (as illustrated in Figure 2) that include 57 items in FAO code and 124 items in HS code. Other data were obtained from AQUASTAT database,[8] including agricultural added values, agricultural water withdrawals, total renewable water resources, and population for major net virtual water exporting nations.

3. RESULTS

3.1 Virtual Water Flows. As illustrated in Figure 1, during 2000-2016, China experienced the shift from a net exporter (26.67 billion m^3 in 2000) to a net importer (42.85 and 79.12 billion m^3 in 2008 and 2016, respectively) of virtual water in the trade with BRI countries with respect to agricultural commodities. It's worth noting that the burgeoning import, soaring from 25.25 billion m^3 in 2000 to 122.79 billion m^3 in 2016, rather than the relatively stable export, incurred the change.

The structure of the virtual water component varied between import and export. Although green water was the main component of virtual water embedded in both import and export products, the proportion in import (88%) was higher than that in export products (82%). In contrast, gray water contributed 11% to the virtual water export compared to only 4% in import. However, the gray water import increased continuously. In 2016 (5.42 billion m^3) it exceeded the export (4.74 billion m^3), while the opposite was observed as both the amount and share of gray water export decreased. As for the blue water, the average proportion was approximately the same (7%) for both import and export, with the former halved from 10% to 5% while the latter increased slightly from 6% to 7% during 2000-2016. Both import and export mainly consisted of green water, and the proportion of gray water in exports was higher from China to its trade partners, although the amount decreased.

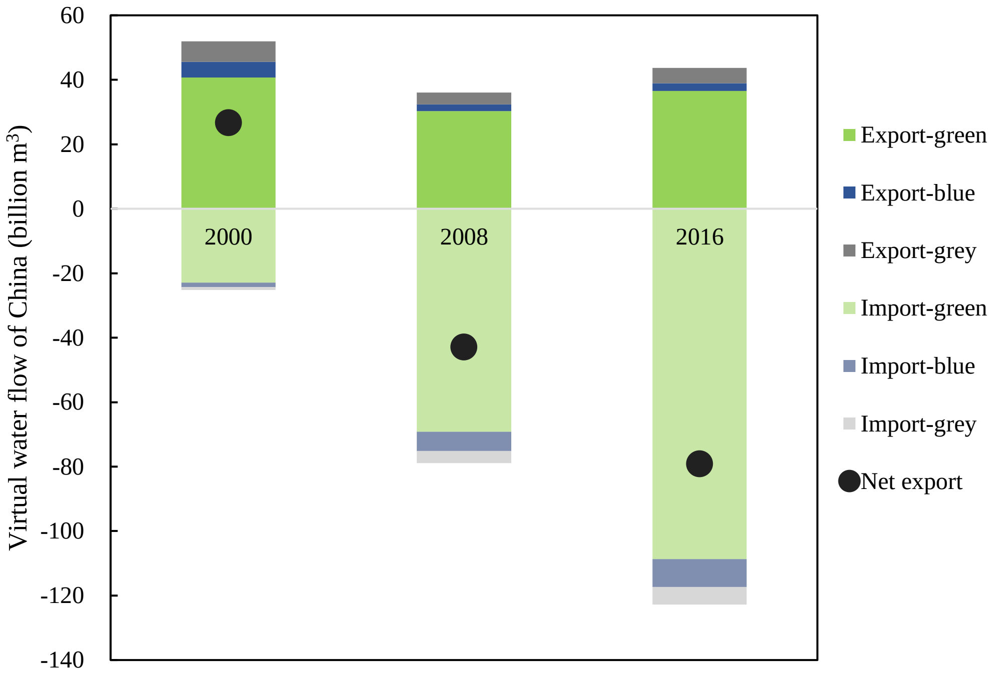


Figure 1. Compositional structure of virtual water flows between China and BRI countries during 2000-2016. “Export” indicates the virtual water flows from China to BRI countries, and “Import” indicates the reverse.

Figure 2 illustrates the product structure of China's imports and exports. The largest share of the virtual water flows from China to other BRI countries was related to trade in cereals (31%) and vegetables (28%). In 2000, China exported 36.21 billion m^3 (70%) in relation to trade in cereals, of which 79% was contributed by maize trade to Korea, Malaysia and Indonesia. However, with the sharp decrease of trade in cereals and increase in vegetables, the major category of export became the latter in 2008 (13.21 billion m^3, 37%) and 2016 (19.27 billion m^3, 44%). The other product categories with a large proportion of annual virtual water export included fruits (13%) and sugar crops and sugar (7%). Trade in vegetable oils (32%) and rubber (28%) together contributed to more than half of the annual virtual water import from BRI countries. Palm oil accounted for approximately two-thirds of the virtual water import among all the vegetable oils. Both vegetable oils and rubber experienced continued increase of virtual water flows during 2000-2016. The other product categories with a large share of annual virtual water import included fibers (10%), cereals (8%) and nuts (5%). Notably, the import of cereals increased dramatically in 2016 due to the rise of the trade in rice and maize.

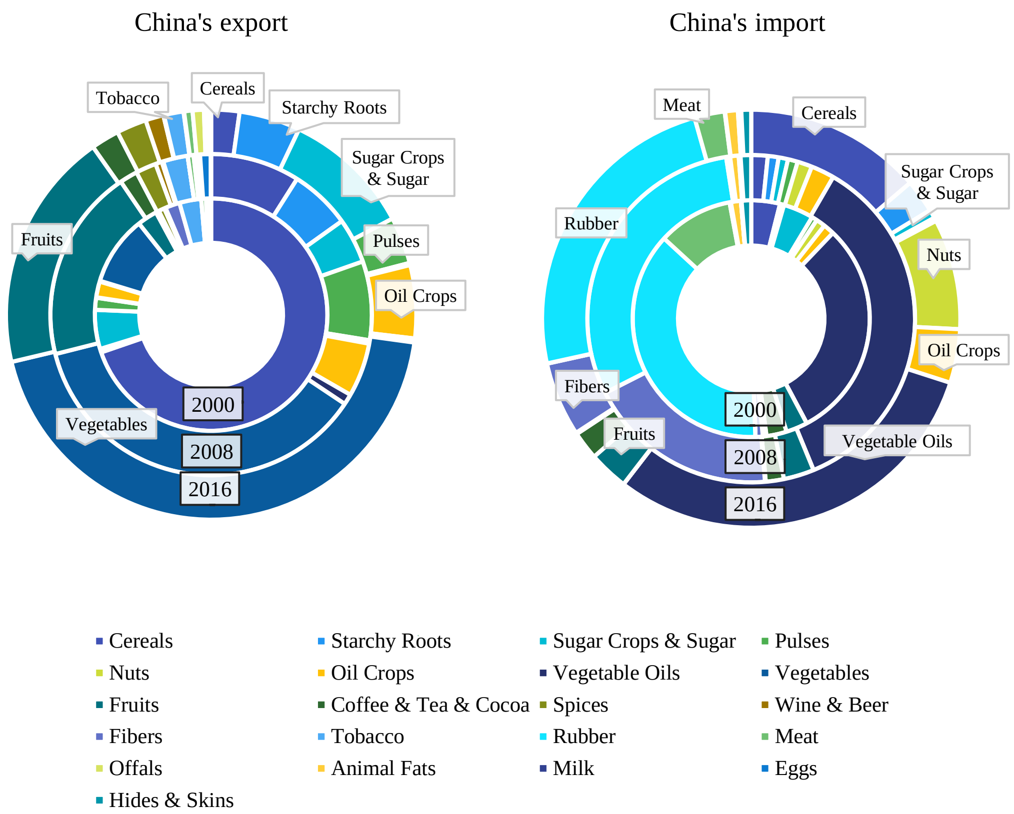


Figure 2. Product structure of virtual water flows between China and BRI countries during 2000-2016. “China’s export” indicates the virtual water flows from China to BRI countries, and “China’s import” indicates the reverse.

Figure 3 illustrates the regional and national virtual water flows. China changed from a net exporter in 2000 to a net importer in 2016 owing to the reversal regarding countries in Southeastern Asia, Southern Asia, Eastern Europe and Africa. In 2008, European countries increased the net virtual water import from China, while Asian and other countries then shifted to export virtual water to China, mainly led by countries in Southeastern Asia and Southern Asia. In 2016, an overall increase of virtual water flow toward China was observed, with the inclusion of flows from Eastern European and African countries, while the net outflow from China was on decline.

The virtual water trade among BRI countries was dominated by the one between China and Asian countries, accounting for over 80% of total virtual water flows in both import and export of agricultural products. Southeastern Asia was the major net virtual water exporter to China, while Eastern Asia was the major net importer with an annual net virtual water flow of 8.77 billion m^3. Accounting for approximately 50% of China's export and 70% of import in total, Southeastern Asia was China's fundamental trade partner under the Belt and Road initiative. Though the virtual water exported to China quadrupled, its share decreased from 80% to 69% during 2000-2016 owing to a 5-fold increase of the total virtual water flow toward China. Alternatively, Eastern Asia, as the biggest net virtual water importer during the study period, experienced a decline of import from China from 2000 (13.13 billion m^3, 25%) to 2016 (7.08 billion m^3, 16%), while its export increased from 0.48 billion m^3 in 2000 to 0.87 billion m^3 in 2016. The virtual water flows between China and Eastern Europe became evident with the sharp increase of import from the latter in 2016. Finally, no obvious change was observed in trade with countries in Southern Europe and Oceania.

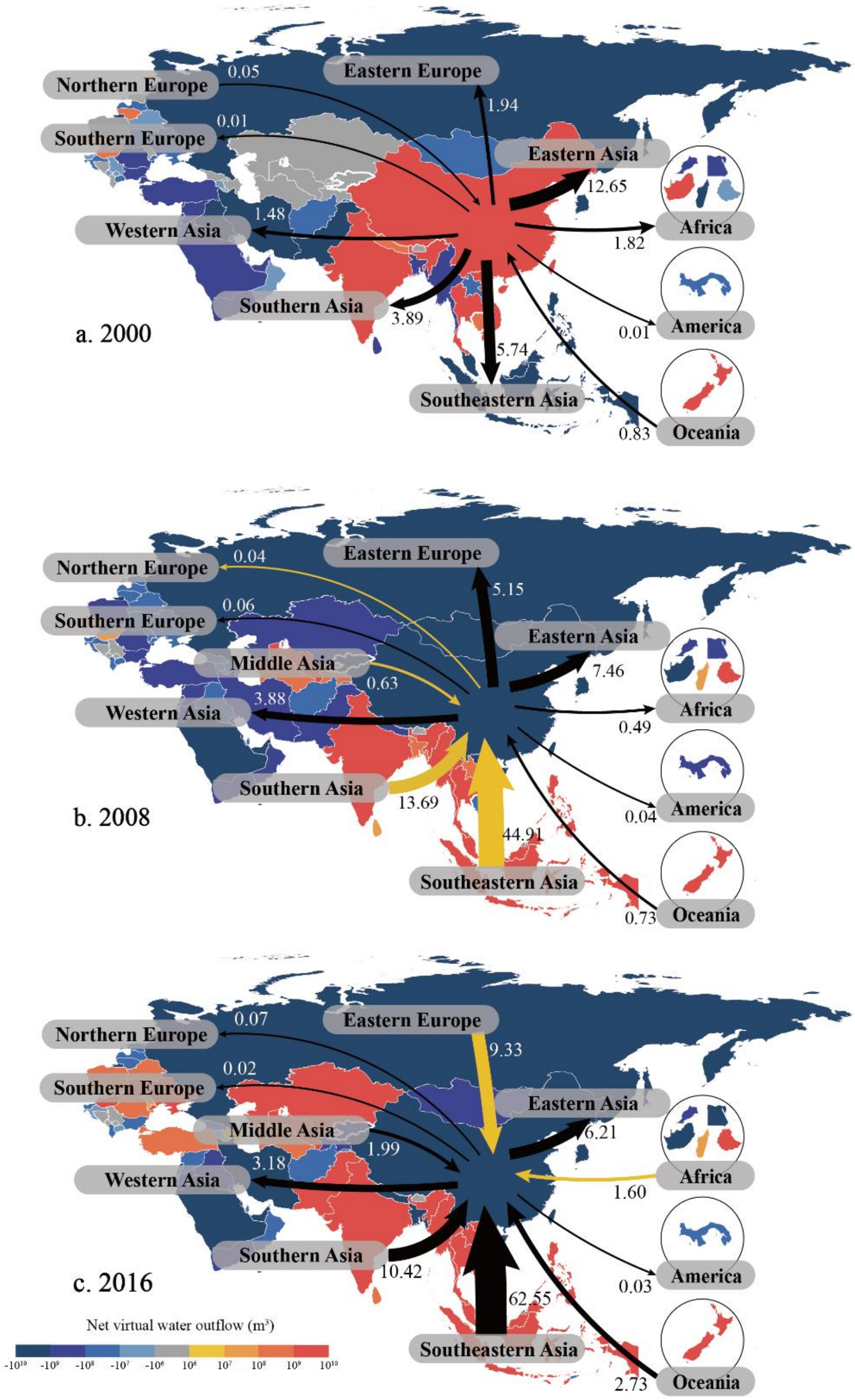


Figure 3. Changes in virtual water flow patterns between China and BRI countries in **a.** 2000, **b.** 2008, and **c.** 2016. The sizes of arrows correspond to the amount of net virtual water flow (billion m^3), and a yellow arrow indicates a reverse flow from the previous year.

3.2 Driving Factors for Exports. To better understand environmental and economic implications of the virtual water trade between China and BRI countries, especially for the major exporters, a decomposition analysis underlying driving factors for the virtual water export was carried out. Figure 4 illustrates the contribution of each driving factor for the virtual water exports from seven countries to China during 2000-2016. Economic structure (i.e. the proportion of trade value in domestic production in agricultural sector) served as a major driving force and water intensity served as a negative one (negative effect presents the factor could decrease country's virtual water export) for most of the export countries, while the contribution of other effects varied (e.g. product structure and water productivity) or was negligible (e.g. water vulnerability, water scarcity, and population). The only exception where the effects of water vulnerability and scarcity were perceptible was the case of Malaysia, the trade scale of which was the largest.

Economic structure and water productivity (i.e. the agricultural added value per unit of agricultural water withdrawal) were the major positive effects (positive effect presents the factor that could increase one country's virtual water export) for virtual water exports to China, with the exception of the economic structure effect for Lithuania. The economic structure effect played a prominent role in the virtual water export from India, New Zealand and Hungary, while for Malaysia the contribution of productivity effect exceeded that of economic structure. Unlike previous conclusions obtained from a global scale, in this research, population was a relatively minor positive effect except for the two European countries, Hungary and Lithuania. An overall decrease in water intensity of exports was observed except for Ethiopia. The effect of water intensity served as a major negative force for New Zealand, India, and Hungary. The product structure effect (i.e. the share of a certain product in the total trade volume) served as a negative force in exports from Malaysia, New Zealand and Lithuania, while for the other four countries it served as a positive one due to an increased variety of export products in 2016. It was the major positive driving force for Ethiopia and Turkey, but the major negative force for Lithuania. During this period, all countries except Hungary experienced increased water pressure issues in relation to either water vulnerability or water scarcity or both as in the case of Turkey and New Zealand, of which the agricultural water withdrawal took up more than half of the total renewable freshwater resource. Among all the effects for each country, the contribution of water vulnerability or water scarcity was relatively minor, with the exception of Malaysia, the two effects of which served as the major negative forces.

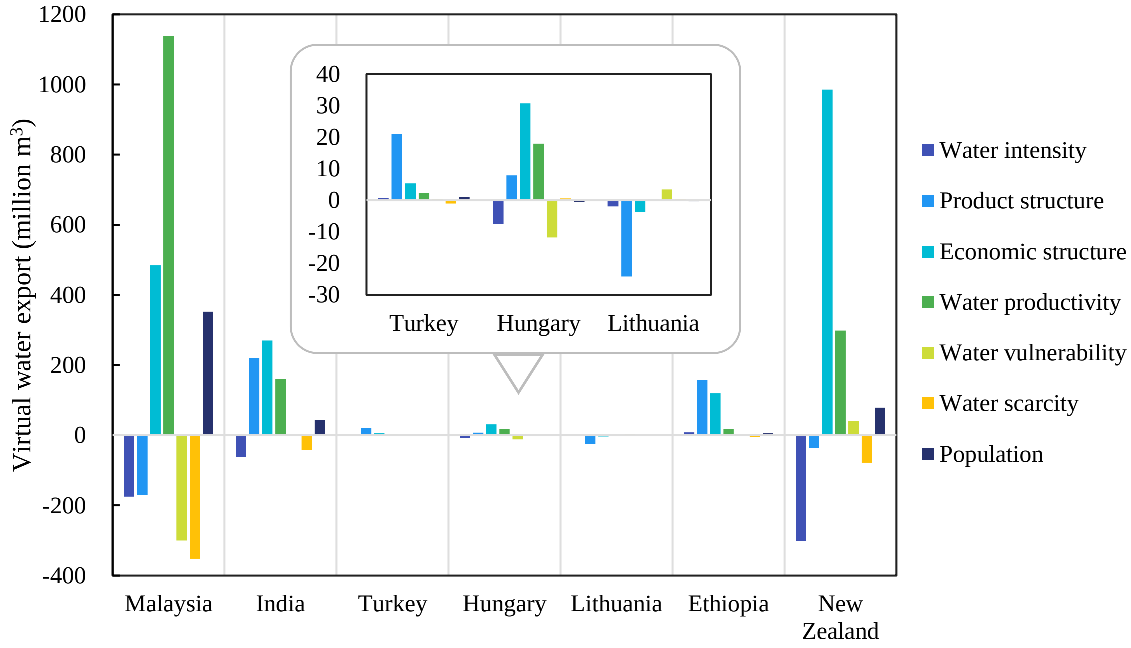
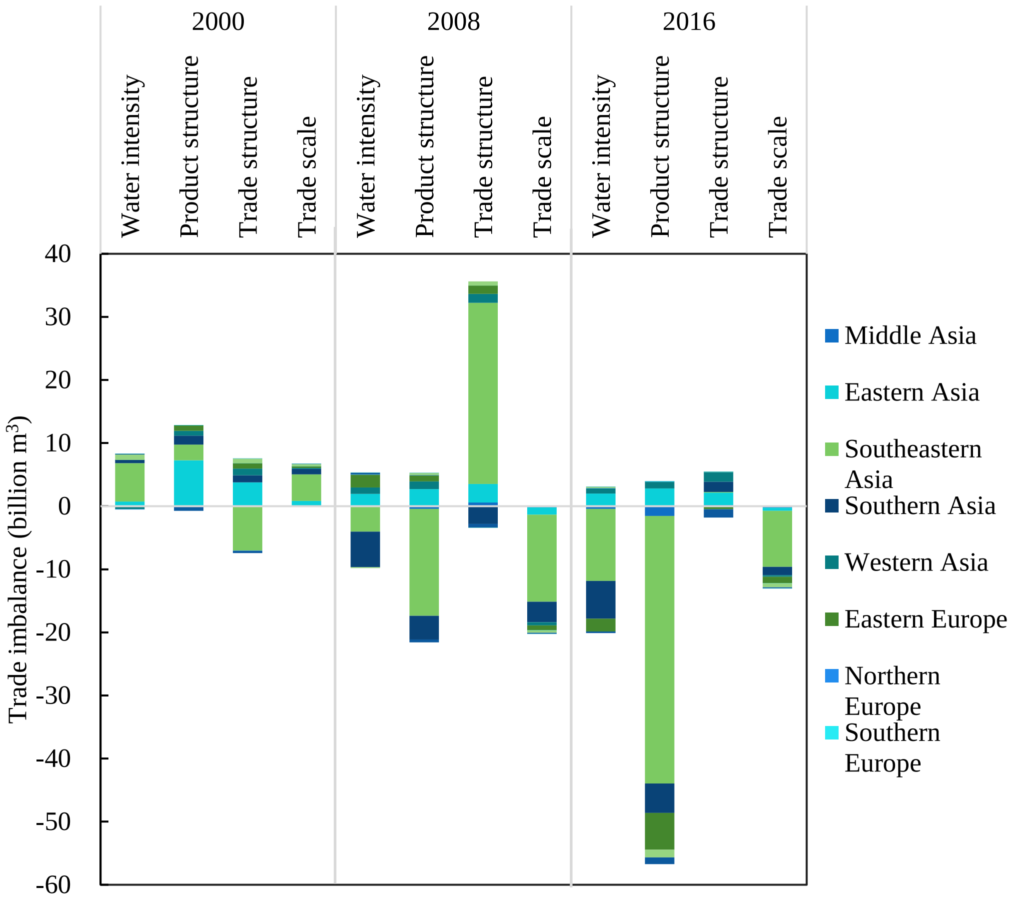


Figure 4. Driving factors for virtual water exports from seven BRI countries to China during 2000-2016.

3.3 Driving Factors for Trade Imbalance. Figure 5 illustrates the contribution of four driving factors to the net virtual water embodied in the trade between China and BRI countries in the years of 2000, 2008 and 2016. Among them, trade structure was the only positive effect throughout this period, peaking at 32.25 billion m^3 in 2008. The effects of water intensity, product structure, and trade scale were positive in 2000 but then reversed in 2008. The effects of water intensity and product structure more than tripled in 2016, while trade scale effect became less evident compared to 2008.

In 2000, China served as a net virtual water exporter, and its four driving forces all contributed positively to the total net virtual water export. Eastern Asia had the highest effects of product structure and trade structure, while the effects of water intensity and trade scale of Southeastern Asia were the highest among all regions. In 2008, Southeastern Asia and Southern Asia were the major regions responsible for the overall shift. The effects of product structure and trade scale were the major negative forces. The import of vegetable oils (palm oil) and rubber from Southeastern Asia and fibers from Southern Asia increased dramatically, while the export of cereals (maize) from China to Southeastern Asia decreased during 2000-2008. During 2008-2016, a major shift occurred for Eastern Europe with the effects of water intensity, product structure and trade scale, changing from positive to negative. The main reason was the increase in import of vegetable oils and cereals, or more specifically, sunflower seed oil and maize, from Eastern Europe.



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366 Figure 5. Driving factors for the trade imbalance by region in 2000, 2008 and 2016.

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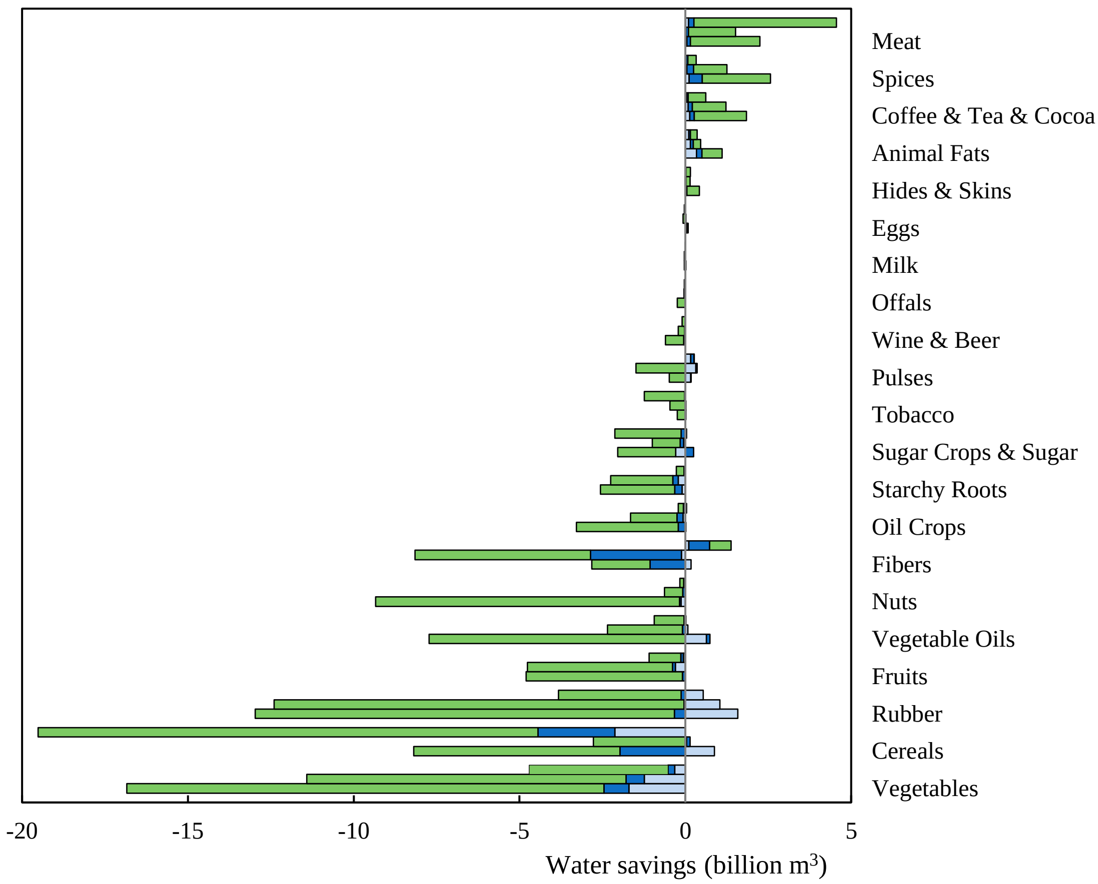
3.4 Global Water Savings. A trade relationship contributes to global water savings if water efficiency is higher (i.e. lower virtual water content) in the exporting nation than in the importing nation, otherwise this would lead to global water loss. Previous research shows that the international trade of agricultural products led to massive global water savings both at a global level during 1986-2007[9] and for China in 2005.[29] Figure 6 illustrates the global water savings due to the trade between China and BRI countries compared with an autarky situation. In this study, the trade between China and BRI countries led to an annual global water loss of 43.14 billion m^3 during 2000-2016. While the total water loss kept increasing along with the green and blue water losses, the gray water loss decreased from 1.48 billion m^3 in 2000 to 0.19 billion m^3 in 2008, and in 2016 reversed itself to a global gray water savings of 1.91 billion m^3.

As shown in Figure 6 **a**., the major trade products with a large annual global water loss include vegetables (10.99 billion m^3), cereals (9.82 billion m^3), rubber (8.68 billion m^3), fruits (3.55 billion m^3), vegetable oils (3.39 billion m^3), etc. Their global water losses increased during this period with the exception of cereals, the water loss of which sharply decreased in 2008. The virtual water trade products with the highest water losses were the exports of maize (in 2000) and onions (in 2008 and 2016) from China to Indonesia and Malaysia. Meanwhile, the trade of certain products contributed to the annual global water savings, including meat (2.77 billion m^3), spices (1.38 billion m^3), and coffee, tea, and cocoa (1.84 billion m^3), etc. The global water savings continued to increase with the exception of meat decreasing sharply from 2000 to 2008. In terms of water components, green water contributes to most of the global water savings or losses, while blue water losses were mainly led by trade of cereals, oil crops, and vegetables. Trade of vegetables (during the study period) and cereals (in 2000) led to gray water losses, while that of rubber (during the period), and vegetable oils and cereals (in 2016) contributed to gray water savings.

The water savings of a certain region in this study encompasses the water savings due to trade between China and this region, from both exports and imports. As shown in Figure 6 **b**., the trade between China and most regions led to massive annual water losses, including Southeastern Asia (26.28 billion m^3), Southern Asia (7.42 billion m^3), Eastern Asia (5.02 billion m^3), etc., while the annual water saving was mainly contributed by its trade with the Oceanic countries, such as New Zealand (1.04 billion m^3), along with Northern European (0.01 billion m^3) and Southern European (0.02 billion m^3) countries. Blue and gray water losses were mainly due to the trade with Southern Asia and Eastern Asia, while gray water savings were due to the trade with Southern Asia and Eastern Europe.

a.


Meat
Spices
Coffee & Tea & Cocoa
Animal Fats
Hides & Skins
Eggs
Milk
Offals
Wine & Beer
Pulses
Tobacco
Sugar Crops & Sugar
Starchy Roots
Oil Crops
Fibers
Nuts
Vegetable Oils
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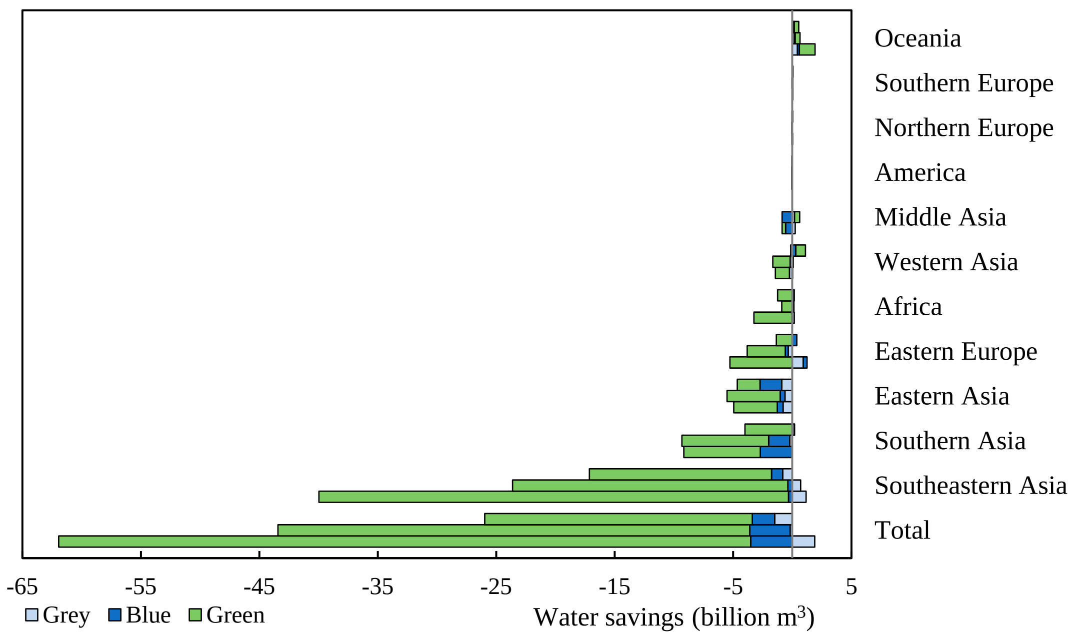
5
Water savings (billion m3)

b.


Oceania
Southern Europe
Northern Europe
America
Middle Asia
Western Asia
Africa
Eastern Europe
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Southern Asia
Southeastern Asia
Total
-65
-55
-45
-35
-25
-15
-5
5
Grey
Blue
Green
Water savings (billion m3)

Figure 6. Water savings by virtual water component due to trade between China and BRI countries in 2000 (upper bars), 2008 (middle bars), and 2016 (lower bars) **a.** by product and **b.** by region.

4. DISCUSSIONS. 4.1. Closer Trade Partnership between China and BRI Countries. As the BRI Initiative claims, the development strategy is proposed to promote connectivity and cooperation. The large scale of more than 70 countries across the world raises concerns about the effectiveness and efficiency of this initiative, e.g. whether China could develop a trade network with most, if not all, of the BRI countries actively involved and provide valuable implications for meeting SDGs and planetary boundaries.

As illustrated in the Results section, China underwent a huge transition in favor of virtual water import from Asian countries in the period of 2000-2008, and reinforced this trend in the following time period. It could be concluded that the trade pattern between China and BRI countries has already been shaped during 2000-2008, with a feature of mainly importing from Southeastern and Southern Asian countries. Such a fact eventually led to a product structure in favor of food import rather than export. In addition, compared with the previous studies, the virtual water embodied in BRI trade summed up to 77.18 billion m^3, which was only 3% of international virtual water flows.[21] Nevertheless, approximately 21% of virtual water inflows to China was from BRI countries.[21]

Concluding from the number of countries involved, the amount of virtual water embodied in trade, and the categories of trade products for each BRI country, most of them became more closely related to China in virtual water trade with time, except for countries in Southern Europe. However, it does not necessarily indicate the overall efficiency improvement in the trade network if it mainly owes to China's expansion on water import. As shown in the decomposition analysis, the trade imbalance was most likely attributable to the product structure rather than a mere expansion of trade scale in 2016, though in 2008 the contributions of the two effects mentioned were comparable, and admittedly, trade scale does positively influence the contribution of each factor. Major shifts in product structure that led to virtual water flow reversals include increase in import of vegetable oils (palm oil from Southeastern Asia and sunflower seed oil from Eastern Europe), rubber (from Southeastern Asia), fibers (from Southern Asia) and cereals (maize, increasing import from Eastern Europe but decreasing export to Southeastern Asia).

Finally, an increase in engagement, trade volume, and product diversity was observed in the virtual water trade network. Under this initiative, a closer trade relationship was created between China and BRI countries.

4.2.Environmental Implications for Global and National Freshwater Resources.

The proposed objective of a virtual water strategy is to alleviate water crises in water-deficit countries. In the BRI context, where natural endowments of freshwater resources vary greatly from country to country, a major environmental concern would be whether the development strategy contradicts the principles of virtual water strategy or otherwise causes massive global water losses. Consistent with former studies,[7] this research uncovers that BRI generally conforms to the virtual water strategy, i.e. the virtual water flows were transferred from water-rich countries to water-deficit ones. However, this trade partnership led to increasing global water losses over the years, indicating the water-inefficiency of this partnership due to evidently lower water-efficiency in virtual water exporters compared to importers. An optimized trade network that contributes to global water savings while satisfying the needs of water-scarce regions is desirable. Given that the virtual water contents in this study are fixed due to data availability, a stronger increase in water efficiency brought about by technological advances and innovation would also have merits. Our study provides evidence on relevant product areas and countries and can help to prepare a more dedicated water efficiency and water stewardship strategy.

Pollution transfer is another concern. In terms of freshwater resource, gray water flows between China and BRI countries were identified to illustrate the water pollution embodied in trade activities. Notably, unlike blue water and green water that represent the freshwater resources, the environmental implications of gray water embodied in trade mainly relate to the exporting countries, as it refers to the external costs for the production of trade products. While the share of gray water was higher in China's exports than in its imports, a decrease was observed in both the amount and share of gray water outflows from China. This shows a mitigation of pollution embodied in trade, and with all the technological advances and relative regulations in prospect, water pollution might be a lesser concern for China.

In addition, the relationship between trade and domestic production is addressed, as intensive trade activities pose extra pressure on domestic water resources to meet increasing demand from trade, which is in competition with domestic consumption. This study focuses on the net export countries that suffer actual water loss but are supposedly less susceptible to it due to abundant natural endowments, instead of net import countries whose water crisis should be, to some extent, alleviated with water supplemented from trade. As shown in the Results section, an economic structure in favor of agricultural product export served as the major driving force for most net export countries, along with the productivity effect. The effects of water vulnerability and scarcity were relatively minor unless the trade scale was large enough. It is recommended that policy makers should help balance between trade and domestic production, and also between economic growth and resource conservation.

4.3 Policy Implications. Based on the results and discussions above, this research proposes the following policy implications, including trade structure optimization, the relationship with domestic production, and international cooperation.

First, Trade Structures and International Supply Chains Shall Address Virtual Water Flows. Up to now, trade activities seldom follow the principles of virtual water strategy due to various economic, geopolitical and cultural factors. However, in order to responds to climate change, water crises and related macroeconomic concerns,[22] international trade policy makers should pay more attention to the risks resulting from water stress and other environmental implications. In particular, in order to respond to Sustainable Development Goals (SDGs) 6 and 12, importing industries and countries should establish water stewardship by promoting trade water efficiency and adjusting trade patterns. As shown in the Results section, product structure and trade structure play an increasingly important role in determining the national imbalance of virtual water trade. In the future, countries should take into account the water resources of their trade partners and the water intensity of trade products when they develop their trade policies. They should reduce massive import from water-deficit countries or import less water-intensive products, so that these countries can mitigate their water consumption.

Second, Resilience to Water Stress Requires Strong Governance Rebalancing Domestic Production and International Trade. In order to reduce water risks in the future, countries should balance between water governance for sustainable production at a domestic level and water governance along international supply chains in order to become more resilient and achieve sustainable and inclusive economic growth. Our study identifies major net exporters and reveals that economic and product structures are the key driving forces for virtual water export, while water intensity can help reduce virtual water export. It would be appropriate to follow water governance principles proposed by the OECD and the World Bank, if countries and supply chain partners across related industries want to reduce the total virtual water export. In this regard stakeholders across the entire supply chains should target to increase water productivity through water-saving technologies, water resource accounting, improved pricing, and governance, rather than simply expanding the trade scale, especially in those less-developed water-poor regions.[38]

Third, International Cooperation Shall be Strengthened and Focus on Water Governance. It is critical to promote international cooperation, especially technology transfer from developed regions to less developed regions and capacity building efforts, so that the overall conservation of global freshwater resources can be achieved. An open data platform with sufficient water and trade information linked with a policy platform to engage with different stakeholders would help policy makers prepare more rational trade policies. Trade partners should also listen to the concerns of different stakeholders through dedicated roundtable discussions and develop risk mitigation strategies. In a world that is increasingly linked by global supply chains, policy makers from different countries should work together to deal with increasing environmental challenges so that potential conflicts can be avoided and the overall water efficiency can be improved.

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