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Research Article

Estimation of the virtual water trade of agricultural products between Vietnam and China

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Abstract: China not only serves as a significant trading partner for agricultural products with Vietnam but also holds a strategic position as an upstream neighbor in Vietnam's major river basins, thereby influencing the nation's water security. This research initially examines the Vietnam-China relationship through the lens of virtual water trade in agricultural goods, analyzing the period from 2010 to 2021. Findings reveal Vietnam's status as a virtual water deficit country vis-à-vis China, a trend that has been progressively worsening. Vietnam acted as a virtual water exporter during this period, exporting around 98 billion m3 to China while importing 10.96 billion m^3. Both nations share similarities in virtual water structure due to similar climatic conditions and technical advancement levels. In terms of product structure, Vietnam emerges as a strategic partner, predominantly supplying China with agricultural products derived from plants. However, this structure lacks balance and is primarily centered around a select few products such as soybean oil (constituting 20.77% of virtual water imports) and manioc starch (constituting 33.48% of virtual water exports). The virtual water trade between Vietnam and China reflects a negative net import, with both countries possessing renewable internal water freshwater resources per capita lower than the global average. While Vietnam currently supports China in addressing water scarcity challenges, diversifying export markets and optimizing the import-export framework with China can enhance Vietnam's resilience and contribute to long-term water sustainability. Consequently, prioritizing policies aligned with the virtual water perspective will empower Vietnam to effectively manage water scarcity, ensuring its future sustainability.

Keywords: Virtual Water Trade; Agriculture Products; Vietnam and China; Virtual Water Defcit.

1. Introduction

Vietnam is a country with a high average rainfall of 1000-4000 mm (2020) [1] and a dense river system with over 2,360 rivers having more than 10 km in length [2]. However, two-thirds of Vietnam's total water resources originate from abroad. If only considering renewable internal water resources, the amount of annual available water will be about 3,719 m^3 per capita in 2020, lower than the world average (5,500 m^3 per capita) [3]. Moreover, Vietnam is situated in a susceptible region positioned downstream of major transnational rivers, which are significantly impacted by upstream nations like Laos and China. Presently, there is a notable increase in the construction of large-scale hydroelectric dams upstream of the Mekong River, resulting in alterations to seasonal flows downstream. This phenomenon impacts the sediment load, triggers floods, and disrupts agricultural and fishery practices [4]. In Vietnam, the study computed the aggregate volume of virtual water expended on four primary crops-rice, corn, coffee, and sugarcane illustrating that reliance solely on domestic water reservoirs would lead to severe water scarcity in regions such as the Red River Delta and the South Central Coast [5]. Consequently, prioritizing the regulation of water resources for Vietnam through inter-country policies to uphold water security emerges as a paramount task. Efforts to mitigate strain on potable water sources have been investigated and put into practical application. Since the 1980s, the notion of "Virtual Water", as introduced by the study [6] has been advocated to quantify the water consumption associated with various goods or food items, necessitating thorough investigation. This approach is regarded as a sustainable method for assessing a nation's water usage concerning goods and food items, thereby offering a clearer and more comprehensive understanding of water resource utilization issues. Addressing scarcity can be facilitated by importing commodities with substantial virtual water content from countries endowed with relatively abundant water resources, thus alleviating strain on local river basins [7].

The trade relationship between Vietnam and China has developed dramatically in the period 2010-2020 [8]. Subsequently, the trade dynamics and commerce between the two nations have fostered a robust relationship, establishing a connection between goods and food. China emerges as a crucial partner in the import-export domain for agricultural commodities, benefiting from Vietnam's geographical proximity, which facilitates reduced transit time and transportation expenses for agricultural products. Leveraging the ASEAN-China Free Trade Agreement (2002), Vietnam has secured tariff reductions for over 8,000 export items, encompassing agricultural products [9]. Hence, based on data from the General Statistics Office, China stands as Vietnam's primary trading partner, leading in both imports and exports. From 2010 to 2020, Vietnam's trade with China escalated from 17.8% to 24.4%, with indications suggesting a potential continuation of this upward trend [10]. Additionally, as per previous research in the period 2001-2014, Vietnam emerged as the leading provider of virtual water to China among nations engaged in the Trans-Pacific Partnership Agreement, including the US, through its exports about 2.72 billion m^3/year, while simultaneously ranking as the second-largest importer of such products from China within this group, accounting for 1.29 billion m^3 per year [11]. This indicates that Vietnam experiences a virtual water deficit in its trade dealings with China. Coupled with Vietnam's reliance on upstream countries for river basins as aforementioned, investigating the virtual water trade between Vietnam and China becomes an urgent priority. Previous reports on virtual water trade had also been carried out by many countries such as Malaysia [12], Spain [13], and the Nile basin [14] to manage water security for countries. Moreover, this represents a new research avenue that has not yet been explored in Vietnam.

The main purpose of the study is to clarify the virtual water trade relationship between China and Vietnam in the period from 2010 to 2021 by examining the specific water footprint of agricultural trade products derived from plants and animals for agricultural products which is the largest freshwater consumption in the world, accounting for about 70-95% [15]. The study seeks to provide an in-depth analysis of the China-Vietnam relationship through the lens of virtual water trade. Additionally, it will utilize the virtual water footprint of various product types to meticulously calculate and present data, shedding light on the trade dynamics between the two nations in terms of product composition and water footprint makeup, with a focus on water sustainability. Following the introduction, section 2 will outline the research methodology, section 3 will present the results and discussion, and section 4 will conclude the study.

2. Materials and Methods

2.1. Method of research

2.1.1. Virtual water calculation for agricultural products

Virtual water, also known as “embedded water” or “indirect water”, refers to the water that is concealed within the products, services, and processes consumed daily by individuals. Despite remaining unseen by the end-user, this water is expended throughout the entire value chain, enabling the creation of the respective product or service. Virtual water and water footprint both concern the water consumption in manufacturing, but the concept of water footprint has broader applications. While virtual water accounts for all water used in a product's production, the water footprint (WF) is the volume of water required to produce an agricultural product which is calculated as three components of water: green water footprint, blue water footprint, and grey water footprint. Additionally, we can evaluate whether a product’s water footprint aligns with local water resources and ecological conditions. The green water footprint pertains to the rainwater utilized during the production of an item, the blue water footprint relates to the surface and groundwater utilized (through evaporation). Additionally, the grey water footprint signifies water pollution, representing the volume of freshwater needed to absorb pollutants based on prevailing ambient water quality standards [5].

The virtual water amount for each crop is calculated based on the specific water needs of the crop and each country with the productivity of that crop [16]. The virtual water content of animal products is calculated based on the following factors: Virtual water content from consumed food, virtual water content from drinking water, and virtual water content from service water [17].

The amount of imported and exported virtual water will be calculated based on the water footprint of that product and that country's agricultural product trade as below:

$$VWF = CT \times WF \quad (1)$$

VWF (Virtual water flows) is the amount of virtual water calculated for products from the exporting country to the importing country or vice versa (m^3/year), CT (The agriculture product trade) is the import or export volume of product (kg/year), WF (water footprint) is the water footprint of that product (m^3/kg) [11].

In determining virtual water trade between Vietnam and China, essential data includes import/export quantities and the water footprint associated with each product. The water footprint of a single product varies across different countries. Therefore, to assess products exported from Vietnam, the study uses the datda of export quantity and water footprint of the Vietnam’s product, while the data of import quatity and water footprint of China is used for the imported products. The virtual water trade volume comprises the green water footprint, blue water footprint, and grey water footprint of the product.

2.1.2. Virtual water surplus and deficit

The concept of “Virtual Water” by [6] is a means to optimize water use through the import and export of virtual water between nations. Virtual water trade enables water-scarce countries to manage water consumption by importing water-intensive products, effectively transporting the water embedded in goods to alleviate scarcity pressure [18]. Conversely, nations abundant in water resources can capitalize on the resources they export [19]. Hence, exporting a product with substantial water usage to another nation constitutes exporting virtual water [16].

The trajectory of a nation's foreign trade can be delineated by its trade surplus and deficit. In international trade, a surplus occurs when a country’s exports surpass its imports within a defined period, whereas a deficit indicates the opposite scenario, thereby reflecting the international balance of payments. Conversely, the computation of virtual water contrasts with the principles of the international balance of payments. A surplus in virtual water trade occurs when a country’s total imported virtual water surpasses its exported volume, and conversely for a deficit. This delineates the equilibrium of water resources. By employing this methodology, we have acquired data on imported and exported virtual water flows between Vietnam and China. If Vietnam's total imported virtual water from China exceeds its exported volume, Vietnam operates under a virtual water trade surplus, and vice versa for a deficit. This approach also facilitates an understanding of the virtual water trade status of individual nations [20].

2.1.3. The assessment indicator of trade partners

This analysis was conducted using two factors. The initial factor, net import, assesses the difference between virtual water imports and exports, indicating either surplus or deficit. The second factor, water abundance, compares each country's renewable internal freshwater resources per capita (measured in cubic meters) with the global average, revealing either abundance or scarcity. If a country's renewable internal freshwater resources per capita surpass the global average in a given year, it is considered abundant in water; conversely, it is deemed to face water scarcity. Renewable internal freshwater resource flows encompass the internal renewable resources within a country, such as internal river flows and groundwater replenished by rainfall. Through the application of these two factors, it becomes feasible to evaluate the dynamics of virtual water management between Vietnam and China.

2.2. Data

2.2.1. Data on import and export of products agriculture

Data on agricultural products exchanged between the two nations are drawn in the period from 2010 to 2021. The year 2010 marks the end of the 10-year socio-economic development strategy from 2001 to 2010, serving as a stary year for subsequent 10-year socio-economic development strategies as per Vietnam's planning [21]. Moreover, the HS code systems have changed since 2021. Therefore, the research has conducted a thorough investigation, providing further insights into the trade dynamics between Vietnam and China, particularly focusing on virtual water trade during the period 2010-2021. Data pertaining to agricultural trade has been meticulously researched and compiled by the International Trade Center (ITC) [22]. ITC provides international trade data by product and country including 99 product groups, this study will focus on agricultural product groups. The data from the ITC are estimated by the United Nations Statistics Unit (UNSD).

2.2.2. Data on the product's water footprint

The calculation will utilize trade data encompassing 339 plant products and 124 animal products. Each product will be assessed based on its green water, blue water, and grey water footprint. These footprint metrics are documented in Mekonnen and Hoekstra's Water Value Research Series No.47 and No. 48, published by the Institute for Water Education (UNESCO-IHE) [23, 24]. Specifically, green and blue water footprint data were computed utilizing the CROPWAT 8.0 model developed by the Food and Agriculture Organization of the United Nations (FAO). However, water footprint data for 126 crops were sourced from MICRA2000 due to the classification dependency on whether the crop is perennial or annual [23, 25]. The grey water factor is determined by the nitrogen fertilizer application and the actual crop yield. Report numbers 47 and 48 employ the 6-digit HS product code for reference; hence, this same code is utilized to retrieve the product quantity data from the International Trade Center (ITC).

2.2.3. Limitations

During the implementation of the study, certain limitations pertaining to data were identified. Specifically, some products changed their HS codes (Harmonized System codes) by the World Customs Organization (WCO) on a 5-year cycle. Consequently, numerous codes became obsolete while new codes were introduced. For instance, the cotton seeds product with code 120720 was replaced by two separate products: Cotton seeds for sowing and cotton seeds, each assigned with distinct codes 120721 and 120729, respectively, in 2007 [22]. Therefore, the study presumed that new codes derived from the same old code would retain the same water footprint and maintain identical characteristics to the previous product code. Furthermore, the study assumes uniformity in the amount of water utilized for irrigation, planting schedules, and crop harvests at the national level, without considering regional disparities within a country. Another limitation lies in the calculation of the grey water footprint, which is based on nitrogen in fertilizers, with natural nitrogen concentrations assumed to be zero. Due to the unavailability of net fertilization rates, it was assumed that crops received an equal amount of nitrogen fertilizer per hectare planted across all grid cells within a country, with an average assumed leaching rate of 10% for fertilizers [23].

Additionally, Report 48 lacks virtual water data pertaining to agricultural products derived from aquatic sources, hence data on this product category was not included in the study. However, seafood represents a significant aspect of Vietnam's import and export activities, prompting consideration for future research on this matter. Furthermore, the study assumes that products are manufactured within their respective countries, and thus utilizes the water footprint of the corresponding country for each product [26].

Despite some limitations encountered in this study, it has successfully estimated the volume of virtual water exchanged between the two countries, aligning with the project's objectives. Moving forward, these identified limitations serve as valuable research avenues that the research team intends to explore in the future.

3. Results and discussion

3.1. Balance of virtual water trade between Vietnam and China

Figure 1.a shows that Vietnam is a virtual water exporter, with the amount of virtual water exported to China reaching 98 billion m^3, and imports from China reaching 10.96 billion m^3 during the entire period 2010-2021. The level of virtual water deficit is increasing rapidly in the period from 1.27 billion m^3/year in 2010 to 9.45 billion m^3/year in 2021 by 7.4 times [22]. The virtual water trade of agricultural products between Vietnam and China has exhibited a notable upward trend over the years, although a substantial disparity exists between exports and imports. From 2010 to 2013, there was a rapid increase in the volume of virtual water exported from Vietnam to China, followed by a stabilization period from 2014 to 2017, and then another increase from 2019 to 2021. Conversely, the amount of virtual water imported from agricultural products remained relatively stable throughout the period from 2010 to 2021. For instance, in 2010, the volume of virtual water imports was approximately 0.65 billion m^3/year, while the export volume was about 1.93 billion m^3. Thus by 2021, the disparity between virtual water imports and exports became more pronounced, with Vietnam importing approximately 1.19 billion m^3 and exporting about 10.65 billion m^3. This indicates a significant increase, approximately 8.9 times higher than the combined import and export volume in 2010. Particularly in 2018, the repercussions of the trade tensions between China and the US led to a general inclination among several nations, including China, to curtail imports of goods wherein Vietnam possessed a competitive edge.

The 2018 Vietnam Trade Report underscores this trend, revealing a notable decline in trade volume between the two countries for various commodities. Notably, there was a decrease in the import of rice (amounting to 638.3 million USD, a decrease of 33.4%) and natural rubber (1.37 billion USD, down by 5%) compared to the figures recorded in 2017 [27]. These agricultural products, which possess a substantial water footprint and constitute a significant portion of the trade volume, consequently experienced a sharp decline in virtual water exports in 2018. For instance, the export of cassava and cassava products totaled 2.15

million tons, marking a decline of 7.3% compared to 2017, with a high water footprint [23, 27]. Hence, the disparity in the quantity of virtual water exports between 2017 and 2018 amounted to approximately 2.57 billion m^3.

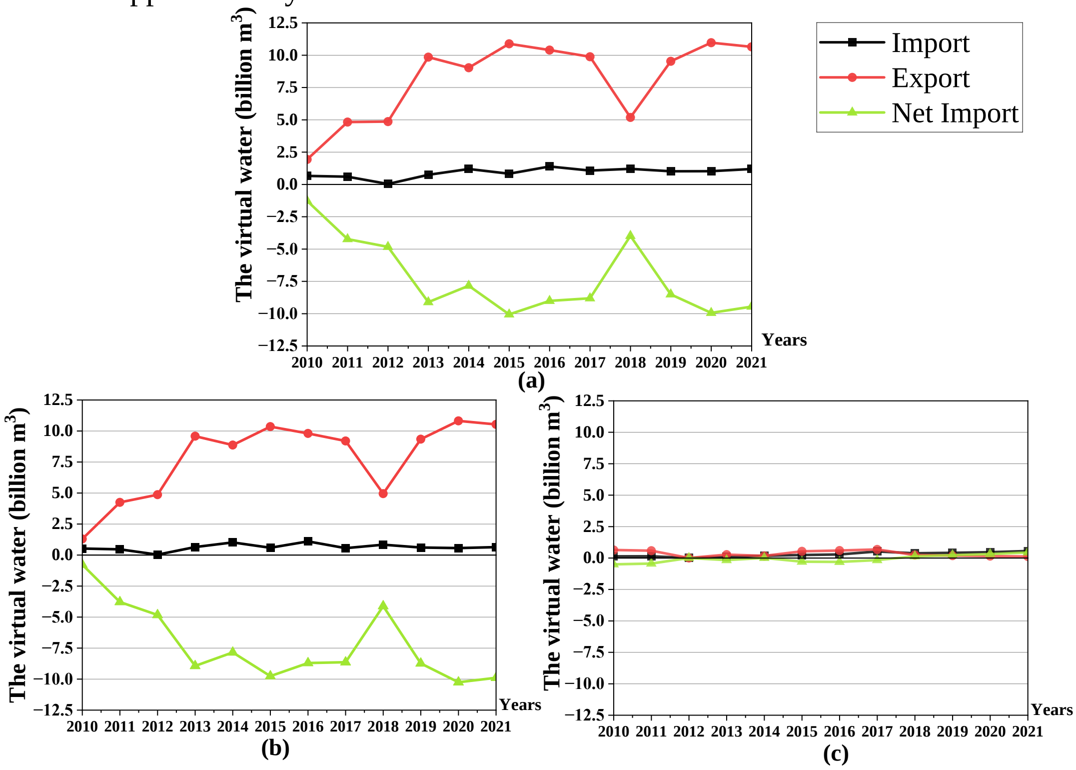

Figure 1. (a) The virtual water trade in agricultural products between Vietnam and China; (b) The virtual water trade in agricultural products derived from plants between Vietnam and China; (c) The virtual water trade in products derived from animals between Vietnam and China.

Vietnam excels in exporting agricultural products derived from plants, hence contributing significantly to the substantial virtual water volume (Figure 1b), exemplified by commodities such as "manioc starch" (32 billion m^3), "natural rubber latex, whether or not prevulcanised" (7.39 billion m^3), "fresh tamarinds, cashew apples, jackfruit, lychees, sapodilla plums, passion fruit, carambola, …" (4.05 billion m^3). The virtual water trade in animal products between Vietnam and China constitutes a notably smaller proportion compared to plant-based agricultural products. The volume of virtual water imported from plant-based agricultural products stands at 7.2 billion m^3, whereas that from animal products is 3.3 billion m^3, marking a 2.18 times difference (Figures 1b, 1c). Nonetheless, during the period from 2010 to 2021, the total virtual water imported from animal-based agricultural products also doubled from approximately 0.6 billion m^3 to 1.2 billion m^3. This underscores the trade relationship's heavy reliance on the exchange of plant-based agricultural products. Two primary factors contribute to the virtual water deficit in the Vietnam-China trade relationship. Firstly, Vietnam boasts a dominant position in exporting key commodities such as rice and cassava. Secondly, China's rapid economic growth has spurred urbanization, triggering population pressures and exacerbating land scarcity for cultivation [11].

3.2. Analysis of the component structure of virtual water trade

The virtual water trade relies on the exchange of three water components: green water, blue water, and grey water. Analyzing the trade involving these water components assists Vietnam in managing water resources effectively, mitigating water deficits in regions facing water scarcity. The general trend showed an increase of virtual water trade in both import and export between Vietnam and China over the years from 2010 to 2021 (Figures 2a_1, a_2,

b_1, b_2), especially a high volume of green water. However, net imports showed a deep downward trend during the study period (Figures 2a_3, b_3, c_3). Beginning at approximately -1.27 billion m^3 of green water in 2010, the exchange of virtual water between Vietnam and China saw a notable increase, reaching about -9.45 billion m^3 by 2021, with a contribution of 8.8 billion m^3 from green water. From 2010 to 2021, Vietnam's imported virtual water structure consisted of 81.2% green water,6.4% blue water, and 12.4% grey water. Conversely, Vietnam's exported virtual water from China comprised 86.9% green water, 4.4% blue water, and 8.7% grey water. In the virtual water trade between Vietnam and China, green water, primarily sourced from rainfall, predominates in agricultural production. Given Vietnam's location in the tropical monsoon region with abundant rainfall ranging from 1000 to 4000 mm annually in 2020, rainwater serves as the primary source for irrigation [1].

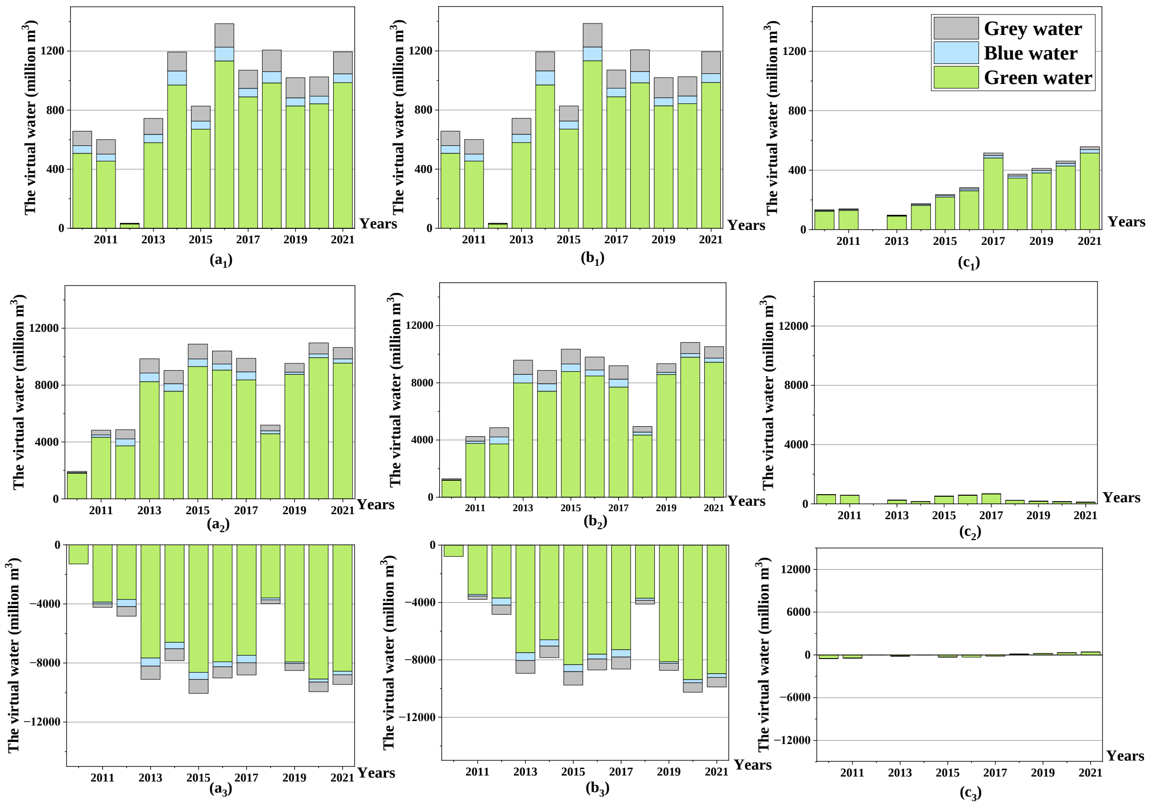

Figure 2. Virtual water structure of imports of all agricultural products (a_1), plant-derived agricultural products (b_1), and animal-derived agricultural products (c_1); Virtual water structure of exports of all agricultural products (a_2), and animal-derived agricultural products (b_2), and animal-derived agricultural products (c_2); Virtual water structure of net imports of all agricultural products (a_3), plant-derived agricultural products (b_3), and animal-derived agricultural products (c_3).

It is clear that the green virtualwater was the highest, and still trend increased in the period 2010-2021.There was a significant decrease in 2012 (Figures 2a_1, 2b_1) due to a lack of data recorded in the ITC [22]. The total import of virtual green water reached a peak at around 1.15 billion m^3 in 2016 (Figure 2a_1). While the total export of virtual green water in 2016 is about 8.7 billion m^3 (Figure 2a_2) including from plant products around 8.1 billion m^3 (Figure 2b_2), and the virtual green water of animal products about is 0.6 billion m^3 (Figure 2b_3). The difference can be explained by Vietnam's advantage in exporting agricultural products especially products derived from plants (Figure 1) and higher green water footprint products of Vietnam than that of China (Table 2). As for virtual water trade in agricultural products sourced from animals, the proportion of green countries accounts for more than the remaining countries. It can be explained due to the high water footpring such as leather "incl. parchment-dressed leather" of the whole hides and skins of bovine "incl.buffalo"... (HS code

410799) has a blue water footprint of 27,203 m^3/ton, 64 times higher than a green water footprint of 426 m^3/ton and 136 times higher than a grey water footprint of 200 m^3/ton [24]. The grey water footprint of agricultural and livestock products is reflected in the grey water footprint of crops in animal feed [23, 24]. Similar to animals products, the majority of the water footprint of plant products is also attributed to green water, for example "natural rubber latex, whether or not prevulcanised" (HS code 400110) of Vietnam has a green water footprint of 14,776 m^3/ton, 92 times higher than a blue water footprint of 160 m^3/ton and 23 times than a grey water footprint of 631 m^3/ton [23]. Furthermore, China encompasses four primary climate zones-desert, polar, continental, and warm temperate [12], resulting in an average rainfall in 2020 of approximately 694.8 mm lower than that of Vietnam. Consequently, China's green water volume is lower than that of Vietnam [28].

The disparity in grey water import and export volumes between China and Vietnam appears relatively minimal, suggesting a similar level of agricultural science and technology between the two nations. Generally, it can be seen that grey virtual water significantly increased both import and export in the period 2010-2021. The large difference in the amount of grey water embedded in the goods traded between China and Vietnam points to the difference in agricultural development levels between the two countries. In 2010, the total grey water import was approximately 0.09 billion m^3 and increased dramatically to 0.15 billion m^3 in 2021. While the total grey water export from Vietnam was about 0.08 billion m^3 in 2010, peaked at 1 billion m^3 in 2015, approximately 0.8 billion m^3 in 2021. Vietnam exhibits a slightly higher grey water footprint, indicating a greater loss of nitrogen fertilizer compared to Vietnam (Figures $2b_1$, $2b_2$).

Table 1. List of 10 agricultural products with the highest export/import virtual water flow between Vietnam and China in the period 2010-2021.

No	Import				Export			
	HS Code	Product	Virtual water (Billion m^3)	Percent	HS Code	Product	Virtual water (Billion m^3)	Percent
1	240110	Tobacco, unstemmed or unstripped	0.2	1.87%	071410	Fresh, chilled, frozen or dried roots and tubers of manioc "cassava", whether or not sliced, etc.	1.8	1.83%
2	410419	Hides and skins of bovine "incl. Buffalo" or equine animals, in the wet state "incl. wet-blue", etc.	0.26	2.42%	520299	Cotton waste (excl. yarn waste, thread waste and garnetted stock)	1.88	1.92%
3	170260	Fructose in solid form and fructose syrup, not containing added flavoring or coloring matter, etc.	0.27	2.46%	090111	Coffee (excl. roasted and decaffeinated)	1.95	2.00%
4	051199	Products of animal origin, n.e.s., dead animals, unfit for human consumption (excl. fish, crustaceans, etc.)	0.34	3.12%	170199	Cane or beet sugar and chemically pure sucrose, in solid form (excl. cane and beet sugar containing, etc.	2.22	2.26%
5	110900	Wheat gluten, whether or not dried	0.36	3.29%	410419	Hides and skins of bovine "incl. buffalo" or equine animals, in the wet state "incl. wet-blue", etc.	2.92	2.98%
6	100610	Rice in the husk, "paddy" or rough	0.37	3.42%	081090	Fresh tamarinds, cashew apples, jackfruit, lychees, sapodilla plums, passion fruit, carambola, etc.	4.05	4.13%

No	Import				Export			
	HS Code	Product	Virtual water (Billion m^3)	Percent	HS Code	Product	Virtual water (Billion m^3)	Percent
7	110710	Malt (excl. roasted)	0.41	3.78%	100640	Broken Rice	5.21	5.31%
8	170220	Maple sugar, in solid form, and maple syrup (excl. flavored or colored)	0.76	6.96%	400110	Natural rubber latex, whether or not prevulcanised	7.39	7.54%
9	410799	Leather "incl. parchment-dressed leather" of the portions, strips or sheets of hides and skins, etc.	2.16	19.69%	100630	Semi-milled or wholly milled rice, whether or not polished or glazed	27.06	27.61%
10	230400	Oilcake and other solid residues, whether or not ground or in the form of pellets, resulting, etc.	2.28	20.77%	110814	Manioc starch	32.81	33.48%

The proportion of the blue water footprint remains relatively small in both imports and exports of animal and plant products. Specifically, in 2010, the volume of agricultural products derived from plants exported with blue water was approximately 0.36 billion m^3 less than the volume of imported products, which contained around 0.46 billion m^3 of blue water. Additionally, animals imported accounted for approximately 0.13 billion m^3 of blue water, whereas the exported volume was around 0.07 billion m^3. The variation between animals and plants arises from the greater number of plant products, totaling 372, compared to animal products, which amount to 124.

Overall, there is not a substantial variation in the proportion of virtual water components over the years. Green water comprises the biggest share, followed by grey water and blue water. Consequently, the percentage breakdown of virtual water import and export for agricultural products between Vietnam and China remains relatively constant.

3.3. Analysis of product structure

During the study period spanning from 2010 to 2021, Vietnam imported approximately 0.05 billion tons of goods from China, while exporting around 0.43 billion tons of agricultural products [21]. This is equivalent to 10.6 billion m^3 of virtual water imported and 97.9 billion m^3 of virtual water exported from Vietnam to the Chinese market.

Vietnam mainly imports agricultural products derived from plants, such as "oilcake and other solid residues, whether or not ground or in the form of pellets, resulting", which accounts for the largest proportion of virtual water at approximately 2.28 billion m^3, constituting 20.77% of the total virtual water import (Table 1). Following "oilcake and other solid residues, whether or not ground or in the form of pellets, resulting" are "maple sugar, in solid form, and maple syrup (excl. flavored or colored)", "malt (excl. roasted)", and "rice in the husk, "paddy or rough", accounting for 6.96%, 3.78%, and 3.42% of the total respectively [23]. Furthermore, the animal product with the highest virtual water proportion in imports is leather "incl. parchment-dressed leather" of the portions, strips or sheets of hides and skins ..." (HS code 410799), amounting to 19.69%, equivalent to 2.16 billion m^3, owing to its high water footprint of 18,628 m^3/ton [24].

Table 2. Variations in the virtual water footprint of individual products between Vietnam and China.

No.	HS code	Product	China (m^3/ ton)			Vietnam (m^3/ ton)		
			Green	Blue	Grey	Green	Blue	Grey
1	230400	Oilcake and other solid residues, whether or not ground or in the form of pellets, resulting	2,114	207	181	2,355	0	308

No.	HS code	Product	China (m^3/ ton)			Vietnam (m^3/ ton)		
			Green	Blue	Grey	Green	Blue	Grey
2	170220	Maple sugar, in solid form, and maple syrup (excl. flavoured or colored)	1,436	54	261	1,853	288	220
3	110710	Malt (excl. roasted)	761	39	194	0	0	0
4	100610	Rice in the husk, "paddy" or rough	549	246	215	1,026	161	205
5	51199	Products of animal origin, n.e.s., dead animals, unfit for human consumption (excl. fish, crustaceans, etc.	80,777	1,412	2,324	87,892	2,092	1,311
6	110814	Manioc starch	1,325	0	293	2,256	0	162
7	100630	Semi-milled or wholly milled rice, whether or not polished or glazed	792	355	310	1,480	232	295
8	400110	Natural rubber latex, whether or not prevulcanised	5,971	359	1,016	14,776	160	631
9	100640	Broken rice	820	367	321	1,531	240	306
10	81090	Fresh tamarinds, cashew apples, jackfruit, lychees, sapodilla plums, passion fruit, carambola, etc.	2,860	90	999	920	0	24

Vietnam's forte lies in exporting plant-derived agricultural products to China, including cassava, rice, rubber, coffee, and fresh fruits. Among these, manioc starch products contribute significantly to the virtual water exported to China, representing 32.8 billion m^3 or 33.48% of the total exported virtual water volume. This prominence is attributed to Vietnam's substantial cassava exports to the Chinese market, with an export volume of approximately 2.26 million tons in 2019 [29] coupled with its substantial water footprint of 2,418 m^3/ton [23]. Additionally, other agricultural products also hold a considerable share, such as "semi-milled or wholly milled rice, whether or not polished or glazed", "natural rubber latex, whether or not prevulcanised", and "fresh tamarinds, cashew apples, jackfruit, lychees, sapodillo plums, passion fruit, carambola, etc.", accounting for 27.61%, 7.54%, and 4.13%, respectively. As for animal-derived agricultural products, wet hides of buffaloes, cows, or horses dominate the export proportion at about 2.98%, with a water footprint of 18,181 m^3/ton.

It is clearly seen from Table 2 that the water footprint of the same product varies between. For instance, for "manioc starch", Vietnam's green, blue, and grey water footprints are 2,256; 0; 162 (m^3/ton), whereas China's green, blue, and grey water footprints are 1,325; 0; 293 (m^3/ton). This disparity stems from differences in national productivity, crop varieties, and local climate, as well as varying agricultural practices between Vietnam and China [23, 24]. Henceforth, Vietnam must contemplate the importation of products characterized by high water footprints while restricting the export of items with substantial water footprints. This strategic approach will ultimately aid Vietnam in alleviating freshwater strain in local regions and guaranteeing water security through prudent product utilization.

The water footprint of animals typically exceeds that of plants due to three key factors: food conversion efficiency, feed composition, and food origin. Higher food conversion efficiency results in less food required for the animal and reduced water wastage during feed production. Feed composition is primarily determined by the types of plants used as animal feed, with the ratio of grain to soybean meal being a key consideration for chickens and pigs. Moreover, the origin of animal feed varies among countries due to regional climate conditions and agricultural practices [22]. As an illustration, consider the export of "hides and skins of bovine "incl. buffalo" or equine animals, in the wet state "incl. wet-blue" (HS code 410419), which amounts to a total volume of 0.02 million tons, equivalent to 0.26 billion m^3. In contrast, the export volume of "fructose in solid form and fructose syrup, not containing added flavoring or coloring matter …" (HS code 170260) is 0.15 million tons, also equivalent to 0.26 billion m^3. Therefore, Vietnam should also consider the virtual trade between plant-derived and animal-derived agricultural products.

In summary, the water footprint of each country is determined by its unique climate, precipitation patterns, and technological advancement, resulting in varying green, blue, and grey water footprints for each type (Table 1). Nations grappling with water issues ought to contemplate importing water-intensive products from regions endowed with relatively abundant water resources to alleviate strain on local water reservoirs [6].

3.4. Analysis of trading partners

The issue of water scarcity is exacerbated due to prolonged droughts or population expansion, resulting in heightened water demands [6]. Virtual water trade is regarded as a viable solution to alleviate the strain on water scarcity while also safeguarding food security and conserving resources [10]. Analyzing trading partners enables Vietnam to gain a comprehensive understanding of its role and responsibilities within the global distribution of virtual water trade.

In evaluating the virtual water trade policy between Vietnam and China, it is crucial to account for two pivotal factors: net imports and the abundance of renewable internal freshwater resources per capita (m^3) as data from The World Bank. For instance, the world average renewable freshwater resources in 2020 were recorded at 5,500 m^3/capita/year, while Vietnam and China reported figures of 3,719 m^3/capita/year and 1,993 m^3/capita/year, respectively [3]. Thus, Vietnam and China are both considered countries with serious water scarcity. The virtual water trade between Vietnam and China entails negative net imports, and China exhibits a water potential below the global average (5,500 m^3/capita/year). Consequently, China receives virtual water trade assistance from Vietnam, as indicated in Table 3.

Table 3. Analysis of trading partners based on net import and water abundance.

Country	Net import (Vietnam)	Water abundance 2020 (m^3/capita/year)	World average (m^3/capita/year)
China	-87.05 billion m^3	1,993	**5,500**
Vietnam	-	3,719	

In general, Vietnam is supporting China in addressing water scarcity issues, but moving forward, Vietnam must refine its import and export strategies concerning agricultural virtual water. Continued expansion of exports to China over time may disadvantage Vietnam and exacerbate water scarcity problems. Therefore, increasing imports of products with high water footprints can assist Vietnam in mitigating water and environmental resource shortages.

4. Conclusion

Vietnam and China are two countries with a close and comprehensive relationship. There have been many studies conducted to explore this relationship from a political and economic perspective, but there is still a lack of research conducted from the perspective of water security. Therefore, the study is conducted comprehensively on virtual water trade between Vietnam and China to better understand from a new perspective. Furthermore, this study presents virtual water flows between two countries considering a full range of factors including trade status, product structure, water footprint structure, and trading partner assessment. From there, it can help Vietnam have policies to adjust the management of trade structures from the perspective of saving water and promoting sustainable use of water resources.

The research findings indicate a significant interconnection in water management between China and Vietnam. China experiences a virtual water deficit sourced from Vietnam through agricultural product imports spanning the period from 2010 to 2021, with a projected upward trajectory in the future. Nevertheless, China is concurrently pursuing a strategy to transition from a net importer to a net exporter in agricultural trade by the year 2050 [30]. Moreover, the virtual water structure of the two countries is similar due to similarities in climatic conditions and levels of scientific and technological advancement in agricultural production. Nonetheless, certain agricultural products, such as cassava, exhibit a higher water footprint in Vietnam compared to China, yet are exported in significant quantities. This necessitates considerations for adjustments in import-export dynamics between regions, particularly for specific products, notably those among the top 10 imports and exports. Additionally, the product structure between the two countries lacks balance, with a predominant focus on certain items like soybean oil (imported) and cassava (exported). Notably, Vietnam contributes significantly to addressing water scarcity through virtual water exports, which are nearly nine times higher than its imports from 2010 to 2021, despite both Vietnam and China possessing considerable potential. However, their domestic water recycling rates are lower than the global average. Thus, it is imperative for Vietnam to prioritize the implementation of policies aimed at mitigating water scarcity by adapting the import-export framework according to the virtual water perspective in the near future.

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