**Water energy nexus under globalization with the implications of trade policy**

**ABSTRACT:**

Water and energy are interlinked, managing them in tandem offers potential for global-change adaptation. However, as conventional conceived the water-energy nexus primarily refers to the water and energy in resource use in production. Such as water footprint of electricity from hydropower on one hand and energy needed to secure water supply on the other hand. The production and consumption are linked through economic chains in an economy, where water and energy are discussed separately. Displacement of water and energy consumption comes about as embodied form in trade. Trade adjustment is regarded as a way to alleviate regional resource crisis in the face of the displacements of resource depletion. However, policies commonly focused on one single resource, lacking a comprehensive assessment of impacts for both resources. Since knowledge on how water and energy interact under the trade pattern can provide important information on resource utilization, it calls for the need to integrate both water and energy together with their conflicting and synergistic interactions under specific policies. This paper establishes a multi-region input-output framework to quantify both water and energy embodied in global trade in differentiated trade scenarios under the corresponding policies, and whether regional scarcity of one resource will be jeopardized when policies only concerning about the other resource. At last, this paper seeks for the ‘win-win’ possibility of trade policy making to achieve both water and energy security.

**KEY WORDS:** water-energy nexus, international trade, export adjustment

# Introduction

Water and energy are recognized as vital inputs to modern economies. Despite the fact that water and energy relies on each other, the woven challenges brought by the nexus between these two resources are always treated isolated from one another [1]. Facing the climate change, integrated regulation based on the recognizing of the reciprocal relation between energy and water shall bring new solution ideas [2, 3].

A series of previous studies have been focused on the nexus of energy and water, however, from the aspect of resource use in production. Such as the energy needed to secure water supply and vice-versa in Middle-East-and-North-Africa area [4], the virtual water content of biofuel in Spain in a bottom-up approach [5], the water footprint of electricity from hydropower [6], and the CO2-Water concept as the water consumption of forest lands for CO2 sequestration [7]. As the production and consumption is linked through economic supply chains, strategies from consumption side shall bring significant assistant in the regulation of resource use. What’s more, globalization tremendously enables resource demands to be fulfilled outside national boundaries via trade of resource intensive products, known as the trade of embodied resource [15-17], while trade of goods or services also transfers environmental pressures from the place of consumption to the place of production, inflicting the risk of resource depletion and environmental quality degradation on the producers. However, on this scale, energy and water are discussed separately. These issues which are generally based on the input-output framework have been presented as the accountings of regional or global water footprint [8-11], and the accountings of regional or global energy consumption or carbon footprint [12-14, 19]. In summary, a knowledge on how energy and water consumption interact under the entire economy via international trade can provide important information for the regulation of resource utilization. As a result, it calls for the need to integrate both water and energy together with their coupling effect in global supply chains.

Learning from the contributions and also the limitations of previous researches, this study first introduce the multi-region input-output framework to analyze both energy and water embodied in international trade within the period from 1995-2009. Using the variables labeled as resource, country and time, an in-depth picture of energy and water transfers is revealed. At last, differentiated strategies of export adjustment are assessed by the reactions of different countries to provide potential choices for export regulations, seeking for synergies between energy and water as well as economy.

# Method and data

The main approaches of multi-regional input-output analysis to evaluate the environmental impacts of trade consist of two models. One is the emission embodied in bilateral trade (EEBT) approach which considers total bilateral trade between regions and cover domestic supply chains. The other is the multi-regional input-output (MRIO) considering imported final consumption as well as tracing the intermediate input across different regions until it is eventually allocated as final consumption, thus the global supply chains. The differences between the two approaches as well as their respective advantages and disadvantages have been analyzed by former studies as the EEBT approach is adopted here to achieve better transparency for the demonstration of resources embodied in global trade [18, 19].

The current study introduce the World Input-Output Database (WIOD) to obtain International MRIO tables and resource data, for the year of 1995 to 2009 [20]. The World Input-Output Database was developed to analyze the effects of globalization on trade pattern, environmental pressures and socio-economic development across a wide set of countries. The database covers 27 EU countries and 13 other major countries in the world. The economic data for the current study is obtained from the World Input-Output Tables (WIOTs) at current prices (35 industries by 35 industries) in the year 2009. The WIOT includes bilateral trade between each country, which is dispatched between industries. So it is possible to use it under simple transformation for EEBT model.

# Results

## Growth of energy and water embodied in international trade

With the development of international trade during the 15 years, global energy use for export has grown from 4.19 Gt in 1995 to 6.75 Gt coal equivalent in 2009 (Gtce), an average annual growth rate of 3.5%. Simultaneously, water embodied in global trade has increased from 434 Gt to 730 Gt with an average growth rate of 3.8% per year (Figure 1). Globalization has intensified the shifts of resources embodied in traded goods and services.



Figure Development of global trade-related indices from 1995 to 2009.

Both embodied energy and water in global trade grew faster that the energy and water use for gross production, which are 1.8% and 2.3% per year, respectively. Undergoing the expansion of production, more and more resources have been involved in trade to fulfill the demand from elsewhere under globalization. Demonstrated in Figure 2, over 30% of energy use and more than 20% water was raised by the production of traded goods and services in 2008.



Figure Ratio of embodied energy (water) in international trade to total energy (water) use in percent 7 [values are plotted as ΔX = (Xt2 − Xt1) / Xt1; t1=1995].

## Global energy and water savings by international trade

As international trade can alleviate the stress of resources in a country through the import of resource-intensive goods or services, nevertheless, our results show that the accumulated influences imposed on global resources from trade are far more complex. The global saving of energy and water through trade in a commodity were introduced as the difference between the resources embodied in imported goods if they were produced domestically (using domestic total resource coefficient) between the actual embodied resources [21]. On global level, international trade could bring not only savings but also loss of resources (Figure 3). The peak loss of energy by trade during this period can be observed in 2000, causing a loss of 0.2 Gtce. The first peak loss of water of 73.2 Gt also appeared in this year. This could be attributed to the boost of international trade value in 2000, along with the resource-intensive technologies whose paces of updating were unable to catch up with the expansion of production for export. The average saving of energy per year is 0.04 Gtce, and for water it is -58.5 Gt. During the 15-year period, international trade has resulted in the saving of energy while however aggravated the situation of global water resources. As the cost of energy generally possesses a large share in the total cost of production for enterprises, international trade seems to optimize the global use of energy. However, due to the real cost of water has been underestimated, which has not been fully internalized in production cost, water is less influential in economic activities under globalization. As a results, huge water is lost despite the saving of energy.



Figure Global energy and water savings through by international trade

## Regional distribution of energy and water consumption and export

According to our calculations demonstrated in Figure 1, a distinct decline for all these variables can be witnessed after 2008 due to the storm of financial crisis as international trade value decreased by 25.7% from 2008 to 2009, which was close to 23% from WTO report [22], bringing the similarly significant reduction of both embodied energy and water in trade by 20.7% and 18.0%. The energy and water embodied in trade snapped back to the level of the time around 2004 due to the shockwave arising in 2008. According to the unavailability of data after 2009, in order to acquire a stable economy for trade analysis, we only focus on the development of international trade from 1995 to 2008.

Besides the strong growth of globally shifted energy and water in aggregated level, the structures of regional consumption and trade has also changed. Similar to the carbon footprint which is the consumption-based nation emission inventory in CO2 domain, the inventory of energy and water for consumption has been calculated for each country. For energy consumption, the USA and China led the top lists in both 1995 and 2008 while the share of China has grown from 9% to 13%. Besides, India’s energy consumption reached 5% of world’s total in 2008 compared to 3% in 1995 and Korea and Brazil appeared among the top 10 list in 2008. China stood still as the top water consumer and India climbed to the 2nd in 2008. It can also be noticed that several developing countries such as Mexico and Indonesia began to show up within the top 10 water consumers. The USA, China, Japan, Russia, Germany and India stood out as both leading energy and water consumers between the two years (Figure 4a). As the export of energy and water, the USA, Canada, China and Russian remained in the top exporters while China has made a massive leap in both energy (from 9% to 18% of total energy in trade) and water (from 15% to 31% of total energy in trade) export, dominating as the most important exporter (Figure 4b).





Figure Regional distribution of energy and water consumption (a) and energy and water embodied in export (b) for 1990 and 2008. Pies with color represent the countries in the top ten lists for both energy and water inventories in both years.

# Discussions

## Shifts in the structure of energy and water export

Based on the changes of consumption and export structure, questions arose as how these aggregated changes were composed. By analogy to the analysis on CO2 emission transfers by Peters, G. P., et al [23], we analyze the regional shifts of energy and water use in the context of developed (Annex B) and developing (non-Annex B) countries under the Kyoto Protocol. However, due to regional resolution of original data in the WIOD database, the Annex B here excludes Croatia, Iceland, Liechtenstein, Monaco, New Zealand, Norway, Switzerland and Ukraine. The results for both Annex B and non-Annex B countries are demonstrated in Table 1. Global consumption of energy has grown from 20.6 Gtce in 1995 to 26.8 Gtce in 2008, an increase of 30% during the period (2.0% per year). And for water, it has risen from 2762.7 Gt to 3771.4 Gt with a growth rate of 2.4% per year. The energy and water embodied in either total production or consumption climbed faster in non-Annex B countries than Annex B countries. The territorial energy and water use for production expanded greater than those embodied in total consumption for non-Annex B countries (3.3% versus 2.7% for energy and 3.3% versus 2.9% for water). The Annex B, however, performed conversely.

Resource flows within Non-Annex B countries performed highest growth rates where the embodied energy grew from 1.4 Gtce to 3.3 Gtce by an annual rate of 9.8% and embodied water grew from 49.9 Gt to 200.2 Gt by an annual rate of 11.3%. This indicates the rapid development of external economy of developing countries, involving more and more resource input. Following are the net transfers of energy and water from non-Annex to Annex, which has also grown rapidly during the period. The net energy transfers has increased from 0.4 Gtce in 1995 to 1.4 Gtce in 2008, 9.8% per year and the net water transfers reached 211.4 Gt in 2008 compared to 89.9 Gt in 1995, 6.8% per year. Similar transfers of other environmental indices have also been witnessed by other studies such as CO2 emissions [23, 24], threats on biodiversity [25] and material flows [26].

Table Transfers of energy and water under the structure of the Kyoto Protocol.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Energy, Gtce | 1995 | 2008 | Growth/year,% | Water, Gt | 1995 | 2008 | Growth /year,% |
| Annex B | B2B | 1.4 | 1.7 | 1.4% | B2B | 146.5 | 171.2 | 1.2% |
|  | B2nB | 0.9 | 1.9 | 5.5% | B2nB | 74.1 | 154.0 | 5.8% |
|  | Bdom | 10.5 | 11.3 | 0.6% | Bdom | 1236.0 | 1465.9 | 1.3% |
|  | Bpro | 12.8 | 14.9 | 1.2% | Bpro | 1456.6 | 1791.1 | 1.6% |
|  | Bcon | 13.2 | 16.3 | 1.6% | Bcon | 1546.5 | 2002.6 | 2.0% |
|  |  |  |  |  |  |  |  |  |
| Non- | nB2B | 1.4 | 3.3 | 7.1% | nB2B | 164.0 | 365.4 | 6.4% |
| Annex B | nB2nB | 0.5 | 1.6 | 9.8% | nB2nB | 49.9 | 200.2 | 11.3% |
|  | nBdom | 5.9 | 6.9 | 1.2% | nBdom | 1092.3 | 1414.6 | 2.0% |
|  | nBpro | 7.8 | 11.9 | 3.3% | nBpro | 1306.1 | 1980.3 | 3.3% |
|  | nBcon | 7.3 | 10.4 | 2.7% | nBcon | 1216.2 | 1768.9 | 2.9% |
| Trade balance | nB2B-B2nB | 0.4 | 1.4 | 9.8% | nB2B-B2nB | 89.9 | 211.4 | 6.8% |

* “B” and “nB” are abbreviations for Annex B country and Non-Annex B country, respectively. “nB2B” refers to the transfer of resources from Non-Annex B country to Annex B country, likewise for other indices such as “B2nB”, “B2B”, etc. “Dom” refers to resources used in production for domestic consumption. “Con” is the total resources used for consumption demand which is trade-adjusted, similar to the concept of consumption-based “footprint”. “Pro” is the total resources used in gross production, including exports, which is the production-based inventory.

To reveal the development in the origins of embodied resources for regional final consumption, the elasticity of the sources of embodied resources to total regional resource consumption was introduced for both energy and water (Figure 5). For Annex B countries, with their growing total consumption for both water and energy, energy and water supported by non-Annex B countries has performed incredibly high elasticity which were 4.34 and 3.17 respectively. Compared with the elasticity of resource input in production for domestic consumption (0.38 and 0.66 for energy and water) which turned out much lower, the fact is clear that the growing demand of developed countries has massively driven the energy and water use in developing countries rather than the resources consumed within their own territories or from other developed countries (0.85 and 0.60 for energy and water).

On the other hand, non-Annex B countries has become more and more dependent on the resource input from other non-Annex B countries. The development of the structure in resource transfers indicates that, although the globalization has enhanced the interdependence of economies which results in the falling self-sufficiency of energy (from 79% to 69% for Annex B and from 81% to 67% for non-Annex B) and water (from 80% to 73% for Annex B and from 90% to 80% for non-Annex B), the developing countries are more susceptible to the growth of external demands of resources.



Figure The elasticity of different origins of embodied energy and water to regional resource consumption.

## Impacts of trade adjustment on resources and economy

Learning that international trade brings different influences on energy and water and the non-Annex B are more sensitive to the growth of trade, this paper has set different scenarios of trade adjustment. The adjustments are focused on energy and water respectively, to examine the response of embodied resources in export to these related trade policies from different aspects. The non-Annex groups are China, Brazil, India, Russia and the rest of non-Annex B. The Annex B groups include the USA, the EU and the rest the Annex B. The scenarios are set as reduce the export values of the exporter by 10% in its top 5 sectors which:

* *Senario1:* perform highest total energy coefficient,
* *Senario2:* perform highest total water coefficient,

with the proportional increase of export volumes in the rest sectors to keep the total export volume constant. Then we examine the changes in exported energy and water and the impacts on the value added (GDP) pulling effects of export under these adjustments of trade structures. The latter is calculated through the same method as we calculated the total input of resources. The only difference is that the GDP here is recognized as output rather than input of an economy. Thus the vector of total GDP coefficient can be derived which represents the value added generated by one monetary unit of final product. The energy and water embodied in export and the induced GDP are then recalculated with adjusted export values and original coefficient. For the sake of demonstrating a picture presenting different regional economies, the effects of trade adjustment are aggregated into 8 world regions from the results in original distribution of regions. The 8 world regions are Brazil, China, India, Russia, the EU, the USA, the rest of Annex B and the rest of non-Annex B.

The percentage changes of the induced indices are illustrated in Figure 6. In Scenario 1, with the control of energy-intensive export, reductions of embodied energy export are witnessed from country to country ranging from 5.4% in Brazil to 1.5% in China. As an important non-Annex exporter, Brazil shows strong potential in the decrement of export-induced energy, followed by the rest of non-Annex B countries (5.2%). The USA (4.2%), the EU (3.9%) and the rest of Annex B countries (3.5%) also show relatively high rates of reduction in energy export. The control of energy-intensive export has brought various rates of water saving. The reduction of exported water ranges from 0.5% in China to 1.8% in Brazil. The energy and water saving in Brazil is quite significant. However, water embodied in export has increased in the USA (0.9%, the biggest increase), the rest of non-Annex B countries (0.4%) and India (0.2%), indicating a trade-off between energy and water export. Fortunately, most countries will experience a decline in both energy and water export. By the calculation of induced GDP, it is surprising that the GDPs have increased for most countries with the regulation of energy-intensive export. GDP in Brazil performs an increase of 0.9%, followed by those in the EU (0.4%) and India (0.3%). Comprehensively reviewing the changes of energy, water and GDP in Scenario 1, it is inspiring to notice that the reduction in export of energy-intensive products can bring the declines in both energy and water as well as bringing increments in GDP in Brazil, China, the EU and the rest of Annex B countries. For some non-Annex B countries such as India and the rest of non-Annex B, the adjustment in export is also instructive as it can bring a huge decline in energy use with a low incremental water use.

In Scenario 2, the focus on water-intensive export has indeed cut the outsourced water in many countries, from 1.3% in China to 7.0% in the USA. All countries perform a reduction rate beyond 4% in water export except China. Besides, compared with the synergetic effect of water reduction brought by energy reduction in Scenario 1, the reduction rates of exported energy in Scenario 2 are far less significant. The reason is that water-intensive sectors are more concentrated in agriculture and light industries such as food and clothing sectors, which have lower energy coefficients, so they are less influential in energy control. On the contrary, energy-intensive sectors are generally heavy industries. They commonly behave to be water-intensive at the same time, such as chemicals sector and other manufacture. Russia stands out as the only country with both high reduction in outsourced energy (2.7%) and water (5.1%) with almost no impact on economy (a 0.006% decrease in GDP). The rest of non-Annex B countries will experience a reduction of 0.2% in energy and 5.8% in water respectively, while enjoying an increase of 0.11% in GDP. The USA also shows up both reduction in energy (0.1%) and water (7.0%, the biggest), meanwhile suffering a slight GDP loss of 0.01%.

Connecting the two scenarios, these countries can be categorized into two groups according to their reactions to different adjustments. The first group including Brazil, China, the EU and the rest of Annex B countries is fit for the strategy in Scenario 1 where the members can perform both energy and water savings with a positive feedback in GDPs. India is also fit for this strategy despite its smallest increase in exported water. On the other hand, Russia, the USA and the rest of non-Annex B countries are better taking the strategy in Scenario 2 where they can also get the outsourced energy and water reduced with few negative impacts on economies.



Figure Changes of export-induced energy (orange), water (blue) and GDP (green) of different groups after trade adjustment compared with present condition in 2008 under Scenario 1 (top: reducing export values of top 5 sectors performing with highest energy coefficient) and 2 (bottom: reducing export values of top 5 sectors performing with highest water coefficient).

Besides, China seems to be less sensitive to the trade adjustments. That is because of its huge export value with relatively adequate distribution on resource-intensive sectors. Undergoing the resource-intensive production, more efforts are left to be accomplished on industrial updating and transformation.

# Conclusions

The past decades have witnessed the boost in world economy and international trade. Along with the expansion of trade, more and more local energy and water resources have been involved into global supply chains. Although previous studies suggested that global trade could help to alleviate the shortage of resources, our analysis manifest that despite the actual savings of energy use, the situation of water resources have become worse. By investigating the origins of embodied resources in trade, we found that the developing countries have been undertaking more and more pressure from resource extraction exerted by external demands. Facing different extents of stress, adjustments of trade for energy-intensive or water-intensive products can bring either synergies or trade-offs to different countries. Such finding is so instructive that it elucidates the fact that differentiated structural adjustment of trade is necessary and of great value for both environment and economy. However, this paper has just provided a crude assessment of trade adjustments only to discover the reactions of different economies when the conservation of energy or water is preferred. More detailed work should be focused on the drivers of those changes under different trade adjustments, as well as more feasible and reasonable setting of trade strategies according to specific economic features and policies.

**References:**

 [1]. Hussey, K. and J. Pittock, The Energy-Water Nexus: Managing the Links between Energy and Water for a Sustainable Future. Ecology and Society, 2012. 17(1).

 [2]. Scott, C.A., et al., Policy and institutional dimensions of the water–energy nexus. Energy Policy, 2011. 39(10): p. 6622-6630.

 [3]. Lim, S. and J.M. Park, Cooperative Water Network System to Reduce Carbon Footprint. Environmental Science & Technology, 2008. 42(16): p. 6230-6236.

 [4]. Siddiqi, A. and L.D. Anadon, The water–energy nexus in Middle East and North Africa. Energy Policy, 2011. 39(8): p. 4529-4540.

 [5]. Elena, G. and V. Esther, From water to energy: The virtual water content and water footprint of biofuel consumption in Spain. Energy Policy, 2010. 38(3): p. 1345-1352.

 [6]. Mekonnen, M., A.Y. Hoekstra and Others, The blue water footprint of electricity from hydropower. Hydrology and earth system sciences, 2012. 16: p. 179--187.

 [7]. Chavez-Rodriguez, M.F. and S.A. Nebra, Assessing GHG Emissions, Ecological Footprint, and Water Linkage for Different Fuels. Environmental Science & Technology, 2010. 44(24): p. 9252-9257.

 [8]. Zhang, C. and L.D. Anadon, A multi-regional input–output analysis of domestic virtual water trade and provincial water footprint in China. Ecological Economics, 2014. 100: p. 159-172.

 [9]. Lenzen, M., et al., International trade of scarce water. Ecological Economics, 2013. 94(0): p. 78-85.

[10]. Steen-Olsen, K., et al., Carbon, Land, and Water Footprint Accounts for the European Union: Consumption, Production, and Displacements through International Trade. Environmental Science & Technology, 2012. 46(20): p. 10883-10891.

[11]. Feng, K.S., et al., Assessing regional virtual water flows and water footprints in the Yellow River Basin, China: A consumption based approach. APPLIED GEOGRAPHY, 2012. 32(2): p. 691-701.

[12]. Liu, Z., et al., Embodied energy use in China's industrial sectors. Energy Policy, 2012. 49: p. 751-758.

[13]. Du, H., et al., CO2 emissions embodied in China–US trade: Input–output analysis based on the emergy/dollar ratio. Energy Policy, 2011. 39(10): p. 5980-5987.

[14]. Liu, H., et al., Energy embodied in the international trade of China: An energy input–output analysis. Energy Policy, 2010. 38(8): p. 3957-3964.

[15]. Hoekstra, A.Y., The Global Dimension of Water Governance: Why the River Basin Approach Is No Longer Sufficient and Why Cooperative Action at Global Level Is Needed. Water, 2010. 3(1): p. 21-46.

[16]. Dalin, C., et al., Evolution of the global virtual water trade network. Proceedings of the National Academy of Sciences, 2012.

[17]. Suweis, S., et al., Water-controlled wealth of nations. Proceedings of the National Academy of Sciences, 2013. 110(11): p. 4230 -4233.

[18]. Peters, G.P., From production-based to consumption-based national emission inventories. Ecological Economics, 2008. 65(1): p. 13-23.

[19]. Peters, G.P. and E.G. Hertwich, CO2 embodied in international trade with implications for global climate policy. ENVIRONMENTAL SCIENCE & TECHNOLOGY, 2008. 42(5): p. 1401-1407.

[20]. Dietzenbacher, E., et al., The Construction of World Input--Output Tables in the WIOD Project. Economic Systems Research, 2013. 25(1): p. 71--98.

[21]. Mekonnen, M.M. and A.Y. Hoekstra, National water footprint accounts: the green, blue and grey water footprint of production and consumption. 2011.

[22]. World Trade Organization, WORLD TRADE REPORT 2009: Trade Policy Commitments and Contingency Measure. 2009.

[23]. Peters, G.P., et al., Growth in emission transfers via international trade from 1990 to 2008. Proceedings of the National Academy of Sciences, 2011.

[24]. Hertwich, E.G. and G.P. Peters, Carbon footprint of nations: A global, trade-linked analysis. Environmental science & technology, 2009. 43(16): p. 6414--6420.

[25]. Lenzen, M., et al., International trade drives biodiversity threats in developing nations. Nature, 2012. 486(7401): p. 109--112.

[26]. Wiedmann, T.O., et al., The material footprint of nations. Proceedings of the National Academy of Sciences, 2013.