Ecological Indicators 47 (2014) 156–163

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

China's unequal ecological exchange

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ARTICLE INFO

Article history:
Received 21 November 2013
Received in revised form 30 January 2014
Accepted 31 January 2014

Keywords:
Local consumption
Global supply chains
Ecological unequal exchange
Multi-region input–output analysis
China

ABSTRACT

Since the economic reform started in 1978, China has experienced unprecedented economic growth and rates of urbanization and associated changes in lifestyles. As a result, China has become one of the world's greatest consumers of natural resources. In a tele-connected world, China's demand for goods and services is increasingly met by global supply chains involving countries that are situated in far geographical distances, and where processes at each stage in the production chain create environmental impacts. On the other hand, China is the world's largest exporter producing goods for the consumption in developed countries. Based on the hypothesis of ecologically unequal exchange that low and middle income countries export natural resources and high impact commodities thus allowing richer countries to reduce ecologically harmful industries domestically, we assess the unequal exchange between China and the rest of world (186 countries) using value added, and four environmental indicators: SO_2 emissions, GHG emissions, water, and land, associated with China's trade relations with the outside world. By using a global multi-region input–output model, we found that developed regions, such as North America, the EU and East Asia including Japan, South Korea externalize environmental impacts through importing goods produced in China. By contrast, less developed regions, such as Southeast Asia, South Asia and Africa, export large quantities of goods and associated SO_2 and CO_2 emissions, land and water to China, but only gain relatively small shares of economic values in exchange. Less developed countries may recognize the value of resources and the cost of pollution and launch stricter environmental policies to prevent further ecologically unequal exchange with developed countries.

1. Introduction

Ecologically unequal exchange posits that natural resources being extracted from poor countries to satisfy consumer demand in richer countries (Moran et al., 2013; Walter and Alier, 2012). In classical economic theory ecologically unequal exchange is a result of specialization and trade (Moran et al., 2013). According to this theory countries would export goods and services for which they have a comparative advantage, with trade allowing for better allocation of resources which in turn is leading to an increase in global social welfare (WTO, 2010). In principle, trade can spatially distribute environmental burden among the least sensitive natural systems, since natural resources such as land are immovable, trade is the only way to spatially match consumption, production, and resources (Van den Bergh and Verbruggen, 1999). However, because of a variety of market failures, natural resources are often under-valued and therefore not allocated efficiently or equitably (Wackernagel and Rees, 1997). Prices may not necessarily reflect real material flows, including the energy and productive potential embodied in these flows, and the environmental and human health costs incurred (Giljum and Eisenmenger, 2004; Hornborg, 1998). There may nonetheless be an unfair exchange of energy, productive potential and sink-capacity demand among trading partners, even in cases where trade is balanced in monetary terms (Andersson and Lindroth, 2001; Rice, 2007).

The ecologically unequal exchange concept is rooted in world-system theory, which assumes that national development cannot be understood if isolated from the global system, where relatively few nations exert great economic and military power (Braudel, 1981; Jorgenson, 2006; Jorgenson and Rice, 2005, 2007; Roberts and Parks, 2007; Wallerstein, 1974). These economically and militarily powerful countries are advantageously situated within the world economy and appropriate a disproportionate share of natural resources as well as externalize the environmental costs of their production, consumption and disposal activities (Bonds, 2012; Rice, 2007; Roberts and Parks, 2007). For example, Prell et al. (2014) assessed the economic gains and environmental losses of US consumption and found that larger shares of value-added are generally prompted within the "core" countries, whereas the opposite effect tends to be experienced in the "periphery"

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http://dx.doi.org/10.1016/j.ecolind.2014.01.044
1470-160X/

countries and highlighted to give a special attention to China which exhibits both "core" and "peripheral" characteristics. Mol (2011) analyzed the environmentally unequal exchange between China as ascending world power and sub-Saharan Africa as peripheral economy and found that significant amounts of China's natural resources are imported from sub-Saharan Africa. Material flow analysis has been applied to examine material flows and emission flows in production processes, and to establish which economic sectors are particularly unsustainable (Giljum, 2004; Machado et al., 2001; Moran et al., 2013). For example, Giljum (2004) found that over the period from 1973 to 2000 Chile's material inputs have increased by a factor of six due to its resource-intensive exports from mining, forestry, fishing, and fruit planting sectors. Thus, these studies suggest that core economies are draining ecological capacity from extractive regions by importing resource-intensive products and have shifted environmental pressure to poorer regions through the export of pollution (Roberts and Parks, 2007). Recent studies assessed virtual water flows and CO_2 emission associated with China's trade with other countries (Guan and Hubacek, 2007; Minx et al., 2011; Zhang et al., 2011). For instance, Zhang et al. (2011) examined impacts of China's international trade of goods and services on its water uses and found that China is a net virtual water exporter. Their study showed that China's water scarce regions tend to have higher share of virtual water export relative to their water resources and water uses, thus suggested that China's economic gains are at the expense of its water resources. Minx et al. (2011) identified driving factors for China's CO_2 emission growth between 1992 and 2007. They found that export demand contributed more than 50% of the CO_2 emission growth (when allocating investment proportionally) between the period of 2002 and 2005 when growth was most rapid in China.

Since the economic reforms started in 1978, China has experienced unprecedented economic growth, industrialization, and rapid urbanization (Chen, 2007). Its export volume increased considerably from $9.8 billion in 1978 to $1.75 trillion in 2010 (The World Bank, 2013a). Now China is the world's largest exporting nation of goods (accounting for 10% of world exports) bypassing the United States and increasing the country's presence in global markets (WTO, 2012). Its total trade in goods and services reached 31% of GDP, compared with 14% in the United States in 2011 (The World Bank, 2013b). China's share of world trade of manufactured goods doubled during the past decade, and China now accounts for 35% of manufacturing imports in Japan, 30% in the European Union, and slightly over 25% in the United States (The World Bank, 2013b).

China increasingly consumes its natural resources domestically as well as abroad to support its massive exports, and meanwhile encounters considerate environmental challenges. Parts of China are facing one of the world's worst water shortages, and China's annual water deficit is roughly 40 billion cubic meters in normal years (Kahrl and Roland-Holst, 2008), which is approximately 14% of China's total water withdrawal (FAO, 2010). The uneven water distribution further exacerbates this problem. However, 8.6% of the water use in China is for production of goods and services for exports (Zhang et al., 2011). In some water scarce areas such as Tianjin roughly 63% of the water use is used for exports (Zhang et al., 2011). In the case of trade of land-based resources, studies found that China is a net exporter (Yu et al., 2013). On the other hand, to meet its rapid economic growth and domestic consumption, driven by income increase and changes in peoples' lifestyles, China needs to import resources from other countries, in particular developing countries, such as Latin America, and Africa, thus externalizes environmental pressures to these countries (Mol, 2011). However, in the past, most studies focused on embodied emissions in China's exports (Feng et al., 2012; Minx et al., 2011; Peters et al., 2007). In addition, it is rare to see studies taking into account both environmental losses and economic gains, with very few exceptions (e.g. Moran et al., 2013; Prell et al., 2014).

In this study, we examine the unequal exchange between China and 186 countries in the world using value added, representing a country's wealth, and four environmental indicators including SO_2, emissions, GHG emissions, water and land, representing environmental impacts associated with China's trade activities with the rest of world. By using a global multi-region input–output table, we are able to link consumption to production along global supply chains.

2. Methods and data

2.1. Multi-region input–output (MRIO) model

The MRIO approach is most often used for exploring economic interdependency of different economies. It has been frequently applied to assess many human-induced environmental issues, such as water use (Feng et al., 2011a,b,c; Yu et al., 2010), land displacement (Steen-Olsen et al., 2012; Weinzettel et al., 2013) and carbon dioxide emissions (Davis and Caldeira, 2010; Davis et al., 2011; Feng et al., 2013; Peters et al., 2011). The main advantage of MRIO analysis is that it is able to capture both direct and indirect environmental impacts along the international trade network (Feng et al., 2011a; Wiedmann, 2009; Wiedmann et al., 2011). Recently, numerous studies have applied MRIO analysis to assess embodied emissions and/or natural resources in global trade quantifying the extent to which consumption in developed countries are relying on production in developing countries, therefore, imposing emissions or environmental pressures to producing countries.

In a MRIO framework, countries are connected through global trade. The technical coefficient matrix A is calculated by $a_{ij}^{pq} = z_{ij}^{pq}/x_j^q$ which represents the inter-sector monetary flow from sector i in country p to sector j in country q; x_j^q is the total output of sector j in country q. Y is a final demand matrix consisting of y^{pq}; y^{pq} refers to a vector of each sector's output produced in country p consumed by the final user in country q. x is a vector of sectoral outputs in all countries.

$$A = \begin{bmatrix} A^{11} & A^{12} & \cdots & A^{1n} \\ A^{21} & A^{22} & \cdots & A^{2n} \\ \vdots & \vdots & \ddots & \vdots \\ A^{n1} & A^{n2} & \cdots & A^{nn} \end{bmatrix}; \quad Y = \begin{bmatrix} y^{11} & y^{12} & \cdots & y^{1n} \\ y^{21} & y^{22} & \cdots & y^{2n} \\ \vdots & \vdots & \ddots & \vdots \\ y^{n1} & y^{n2} & \cdots & y^{nn} \end{bmatrix}; \quad x = \begin{bmatrix} x^1 \\ x^2 \\ \vdots \\ x^n \end{bmatrix},$$

Therefore, the MRIO framework can be written as:

$$x = Ax + Y \tag{1}$$

To solve x, we obtain

$$x = (I - A)^{-1} Y \tag{2}$$

where $(I - A)^{-1}$ is the Leontief inverse matrix, which captures both direct and indirect inputs to satisfy one unit of final demand in monetary values; I is the identity matrix. To calculate the embodied environmental impacts in goods and services, we extended the MRIO table with environmental coefficients by using different environmental indicators in Eq. (3).

$$T = F(I - A)^{-1} Y \tag{3}$$

where T is a matrix representing different environmental indicators. Each element, f_{kj}^p, in matrix F represents direct emissions or resource use per unit of economic output of each sector, which are derived from emissions and resource consumption of each sector divided by the respective sector's economic output (see Eq. (4)).

$$f_{kj}^{p} = \frac{e_{kj}^{p}}{x_{j}^{p}} \tag{4}$$

Here e_{kj}^{p} is the environmental indicator k consumed or emitted by sector j in country p; x_{j}^{p} is the total economic output of sector j in country p.

2.2. Data sources

In this study, multi-regional input–output tables were gathered from the EORA multi-region IO database, which provides a time series of high resolution input–output tables with matching environmental and social satellite accounts for 187 countries, each with 26 sectors (Lenzen and Kanemoto, 2012). Data on SO_2, CO_2 emissions and water use were collected from the EORA MRIO database, which provides multiple sources of data at sectoral level for 187 countries. For instance, GHG and SO_2 emissions were extracted from the UN Statistical Division and EDGAR (European Commission Joint Research Center/Netherlands Environmental Assessment Agency, 2009). Water footprint data were extracted from the WaterStat database (Mekonnen and Hoekstra, 2010, 2011). We used the latest available data, i.e. 2010. The land data was taken from Yu et al. (2013), who calculated assembled sectoral land using multiple databases including GTAP (GTAP, 2012), FAOSTAT (FAO, 2012), World Resources Institute (WRI, 2000) and the Corine land cover database (EEA, 2011).

However, we also need to highlight the data uncertainties in this study. First, using MRIO based on the EORA database may result in data uncertainty because of sectoral aggregation. In the EORA database economic sectors are highly aggregated into 26 sectors for each country while the commodities in international trade are several thousand. As a result, a stronger homogeneity assumption exists at the sector level. However, it provides other advantages. For instance, the MRIO tables are able to show the trade flows not only among 187 countries, but also among the sectors in different countries, which enable us to capture the total economic requirements and associated natural resource use along global supply chains. Second, the number of raw data items that can serve as support points for the construction of MRIO table, is much smaller than the number of MRIO table elements. The initial IO table is constructed and then balanced to conform information contained in the raw data items. This process creates undesirable outcomes. More details are provided in Lenzen and Kanemoto (2012).

3. Results

Our results show that the trade balances for different economies in terms of virtual SO_2, CO_2 and water and land shows different patterns from each other and from the balance of trade in economic terms (Fig. 1a–d). The large flows of good and services measured in economic terms from China to developed countries including North America (including the U.S., Canada and Mexico), the EU and East Asia (List of countries see Appendix Table A.1) are matched by large amounts of virtual SO_2 and CO_2. However, the picture in terms of virtual water and land flows with different countries looks different. For example, in some regions, such as Southeast Asia, South Asia and Africa, the deficit in the net virtual water flows shows the opposite direction to the deficit in the economic balance of trade. The net exports in economic terms from China to Southeast Asia, South Asia and Africa are accompanied by a net export of virtual water from these regions to China. This is because China imports large amounts of water intensive products, mainly Agricultural products and Construction-related production, from these regions. A similar situation is observed in terms of net virtual water flows in virtual land and value added between China and non-EU Europe, Oceania, Latin America and Africa. In those regions, the net flows in virtual land is opposite to the balance of trade in economic value, and the economic value in export from China to those regions is disproportionally smaller than the large net export of virtual land from those regions to China.

Our results also show a significantly uneven ecological exchange in terms of total virtual SO_2 associated with trade between China and richer countries, including North America, the EU and East Asia. For instance, as the largest trading partner, China's exports to North America create a large amount of SO_2 (2784.5 thousand tons) in China, while China's import only induces relatively small amounts of SO_2 (about 82.8 thousand tons) in North America. This is mainly due to the huge trade imbalance between the two regions, but also China's current trade patterns with other developed countries when producing low value added but high pollution products. For example, generation of exports from China to North America are 12 times as SO_2 intensive than goods produced in the US imported into China, and 15 times when comparing China's SO_2 intensity with the EU (see Appendix Fig. A.1). This is due to China exporting large amounts of emission intensive goods such as Machinery and Equipment, and Textile and Wearing Apparel to these developed regions, and generating considerable SO_2 and CO_2 emissions domestically (Fig. 2). By contrast, the relationship between China and less developed regions, such as Africa and non-EU Europe is quite different in that imports into China from those regions are about 10% more SO_2 intensive than imports. Thus China causes pollution in non-EU Europe, Africa and Southeast Asia, through importing SO_2 intensive products such as Construction-related production and Petroleum, Chemical and Non-Metallic Mineral Products (Fig. 2).

In terms of virtual CO_2 in trade, China is a net exporter with most trading regions, except Africa where China is a net importer. The virtual CO_2 in trade between China and less developed regions, especially Africa, shows a very disproportionate ecological exchange (Fig. 1b). For instance, generation of exports from Africa to China are 4 times as CO_2 intensive than goods produced in China exported to Africa. By contrast, China has a disadvantaged position in terms of CO_2 in trade with richer countries such as the EU, North America and East Asia. In less developed regions, China and Southeast Asia and non-EU Europe have a relatively neutral virtual CO_2 balance in export and import.

For the water footprint indicator, we observe a very different pattern from the other two indicators (Fig. 1c). China becomes a net importer of virtual water from most regions, especially other Southeast Asian countries, Africa and South Asia. Virtual water in imports from Africa to China is 18 times and from South Asia 15 times as water intensive than goods produced in China exported to these regions. This is due to the huge import of water intensive products, mainly Agricultural products and Construction-related production, from Africa and South Asia (Fig. 2). However, East Asia, the EU and Middle East & Central and West Asia have different trading patterns with China in terms of virtual water. China is a net exporter of virtual water to these three regions. That is because China exports resource intensive products, such as Textile and Wearing Apparel, Machinery and Equipment as well as Services to these three regions, therefore consumes a great amount of resources within its territory to satisfy consumers' demands in those regions.

Similar to the patterns shown with regards to virtual water, China is a net importer of virtual land from many regions, in particular from non-EU Europe, Oceania and Africa (Fig. 1d) to satisfy its demand on Wood and Paper, Construction and Agricultural products (Fig. 2). Land intensity in imports from non-EU Europe is very high, approximately 9 times higher than from China to non-EU Europe, followed by Africa and Oceania, 7 times and 5 times higher

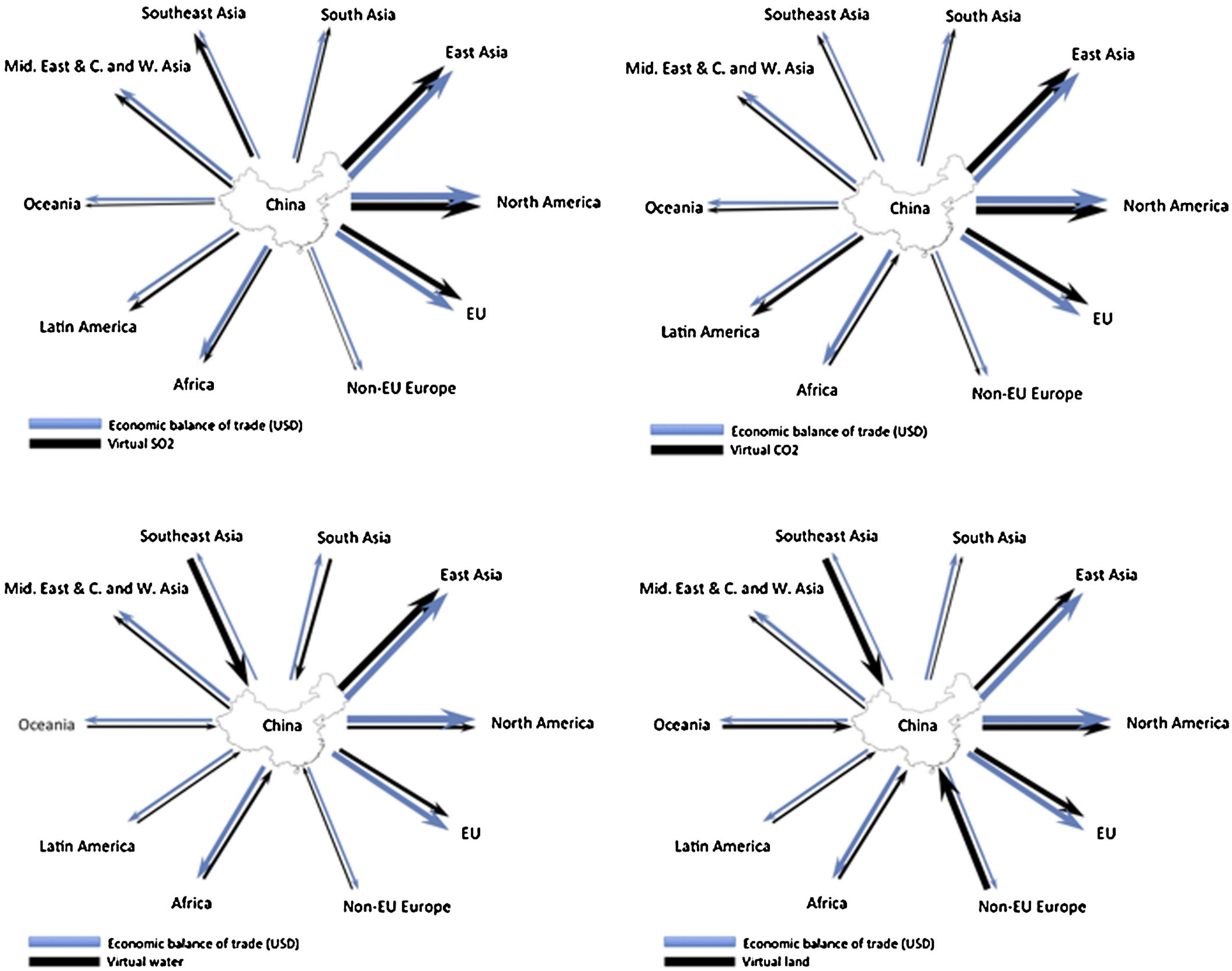

Fig. 1. Virtual SO_2, CO_2, water and land and value added associated with China's net exports to other regions. Black arrow – SO_2, CO_2, water and land; blue arrows – value added. Arrow direction represents virtual SO_2, CO_2, water and land as well as economic value associated with net exports is generated in China. Thickness of arrows represents the volume of trade in economic and biophysical terms, respectively. In all cases the balance of trade in embodied SO_2 and CO_2 is as same as the balance of trade in economic terms. In a few cases (e.g. China to Africa and non-EU Europe), the balance of trade in virtual water and land is opposite the balance of trade in economic terms (different arrow direction). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

in land intensity associated with their exports to China respectively (see Appendix Fig. A.1 data). The reason is that China imports large amount of forestland from Russia and Africa to satisfy its huge demand on construction and infrastructure. Latin America also exports considerable amounts of virtual land to China for its demand on Agricultural products (Fig. 2). By contrast, land intensity for the production of imported goods from the EU and East Asia to China is considerably smaller than goods exported from China to these regions, only about 1/20th and 1/10th respectively.

Overall, China exports a large amount of virtual water and land to developed regions, including North America, the EU and East Asia, which means that China uses substantial domestic land and water resources in order to satisfy these regions' demands for goods and services. Meanwhile, net exports from China to developed regions contain large amounts of virtual SO_2 and CO_2 to satisfy consumption in developed regions.

Fig. 2 shows virtual pollution and resource use in China's import and export with ten global regions for 12 aggregated product categories. China exports large amounts of Machinery and Equipment and Textile and Wearing Apparel to rich regions including North America, the EU and East Asia, and generates considerable SO_2 and CO_2 emissions domestically. While China imports SO_2 and CO_2 intensive products such as Construction and Petroleum, Chemical and Non-Metallic Mineral Products from non-EU Europe, Africa and Southeast, thus causes pollution in these regions. It is also interesting to note that China's consumption causes considerable amounts of virtual SO_2 and CO_2 emissions in East Asia, mainly due to its imports of Machinery and Equipment, although China generates large amounts of emissions in total within its territory to export goods and services to East Asian countries, such as Japan and South Korea. In terms of exchange of natural resource i.e. water and land, China imports great amounts of resource intensive products such as Agricultural products and Construction from Southeast Asia, Africa and South Asia, thus consumes much water and land in those regions. By contrast, China exports resource intensive products, such as Textile and Wearing Apparel, Machinery and Equipment as well as Services to North America, East Asia, the EU and Middle East & Central and West Asia, therefore consume a great amount of resources within its territory to satisfy consumers' demands in those regions. Moreover, non-EU Europe and Oceania are the major regions that export great amount of land to China to satisfy China's need on Wood and Paper, Construction and Agriculture

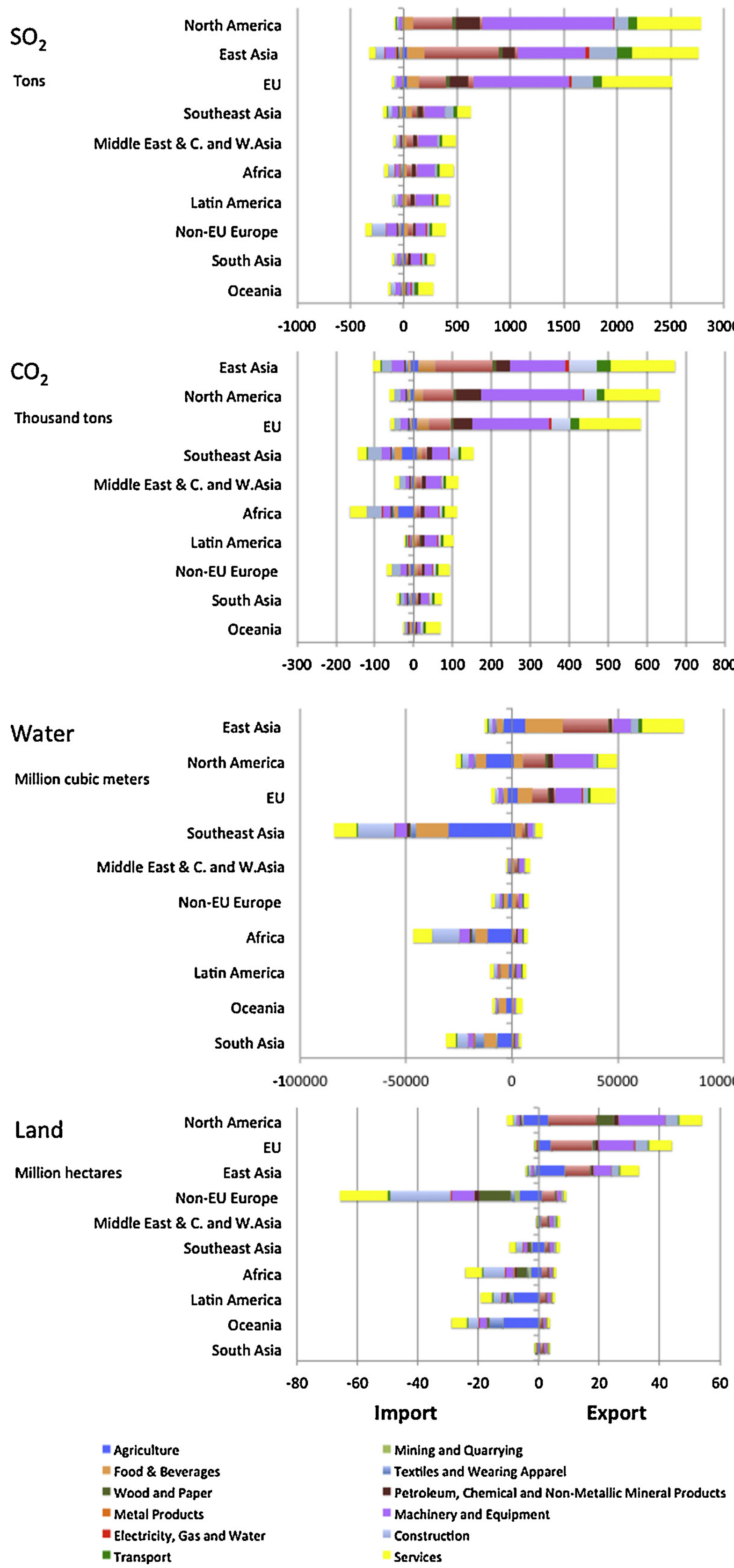

Fig. 2. Virtual SO_2, CO_2, water and land in China's import and export with ten global regions. The left bar shows the import from those regions to China and right bar shows the export from China to those regions (from large to small). *Note*: for illustrative purpose, 26 sectors from MRIO analysis are aggregated into 12 sectors.

products. Latin America also exports considerable amounts of land to China for its demand for Agricultural products. Again, in terms of natural resource exchange, there is ecologically unequal exchange between China and these less developed countries as well as with developed North American and European countries. As China appropriates a large amount of natural resources via trade from the former, but its resources are appropriated by the latter.

4. Conclusion

Our results demonstrate an asymmetrical exchange in terms of economic values and virtual SO_2, CO_2, water and land in international trade. Developed regions, such as North America, the EU and East Asia including Japan, South Korea, Taiwan, Hong Kong etc. externalize environmental degradation through importing goods and services produced in other, mainly lower-income countries such as China. By contrast, less developed regions, such as Southeast Asia, South Asia and Africa, export large quantities of goods and services to China and generate much SO_2 and CO_2 emissions and consume water and land resources domestically, but only gain relatively small shares of economic values in exchange. This uneven ecological exchange dynamics reveals the disproportionate consumption of natural resources by developed regions at the expense of less developed countries. In other words, consumers in rich countries have the opportunities to consume more goods and services at the (environmental) expense of less developed countries. But because their environmental impacts are separated from their consumption, they may not be aware and make sensible choices to reduce their ecological impacts. Moreover, the ecologically uneven exchange also diminishes the opportunities of less developed countries to achieve socioeconomic stability and domestic ecological protection (Jorgenson and Rice, 2007).

By using the MRIO approach, we are able to trace resources use and environmental impacts along entire global supply chains. The four environmental indicators we used in this paper help capture the ecological dimension of trade, and to understand the ecological costs encountered during the extraction, production, distribution and consumption of natural resources. Those costs nevertheless are not reflected during trade and often borne by the exporting countries. In our case, the trade flows are unequal in biophysical terms. Where developed countries are benefitting from the exchange in ecological terms while less developed countries are disadvantaged by the same exchange. Therefore, using different measures can demonstrate a more complex and varied relationship in international trade (Hermele, 2010). Tracing virtual emissions and resources along the global supply chains induced by consumption can help consuming countries to understand both direct and indirect resources use and environmental impacts of their consumption, thus can be used for Chinese government to be aware of the value of resources to launch more stricter environmental policies to prevent further ecologically unequal exchange with developed countries, and at the same time, better manage their global environmental impacts domestically and abroad. In particular, with the continuing growth of China's economy and urbanization, China will need more resources to meet its needs of growing domestic consumption and export will shift some environmental pressure to other countries. Therefore, it will be a big challenge to manage world natural resources efficiently to meet the increasing consumption in China and less developed countries. In an increasingly interconnected world, trade connects production and consumption but at the same time distances consumption from impacts on foreign ecosystems. The consumption-based perspective of resources use and pollution presented in this paper shows an alternative to the production-based accounting by potentially shifting (some of the) responsibility for environmental pressures to consumers as primary beneficiaries, and play an important role informing governments and consumers about the consequences of their consumption choices.

Appendix A.

Table A.1
List of regions and countries.

Region	Country
Oceania	Australia, Fiji, French Polynesia, New Caledonia, New Zealand, Samoa, Vanuatu
Southeast Asia	Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand, Viet Nam
East Asia	North Korea, Hong Kong, Japan, Macao SAR, Mongolia, South Korea, Taiwan
South Asia	Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, Sri Lanka
Middle East & Central and West Asia	Armenia, Azerbaijan, Bahrain, Georgia, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Gaza Strip, Oman, Qatar, Saudi Arabia, Syria, UAE, Yemen
North America	Bermuda, Canada, Greenland, Mexico, USA
Latin America	Antigua, Argentina, Aruba, Bahamas, Barbados, Belize, Bolivia, Brazil, British Virgin, Cayman Islands, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guatemala, Guyana, Haiti, Honduras, Jamaica, Netherlands Antilles, Nicaragua, Panama, Papua New Guinea, Paraguay, Peru, Suriname, Uruguay, Venezuela
EU	Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, UK
Non-EU Europe	Albania, Andorra, Belarus, Bosnia and Herzegovina, Iceland, Kazakhstan, Kyrgyzstan, Liechtenstein, Monaco, Montenegro, Norway, Moldova, Russia, San Marino, Serbia, Switzerland, Tajikistan, TFYR Macedonia, Turkey, Turkmenistan, Ukraine, Uzbekistan
Africa	Algeria, Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Congo, Cote D'Ivoire, DR Congo, Djibouti, Egypt, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Kenya, Lesotho, Liberia, Libya, Madagascar, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Rwanda, Sam Tome and Principe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, Swaziland, Togo, Trinidad and Tobago, Tunisia, Uganda, Tanzania, Zambia, Zimbabwe

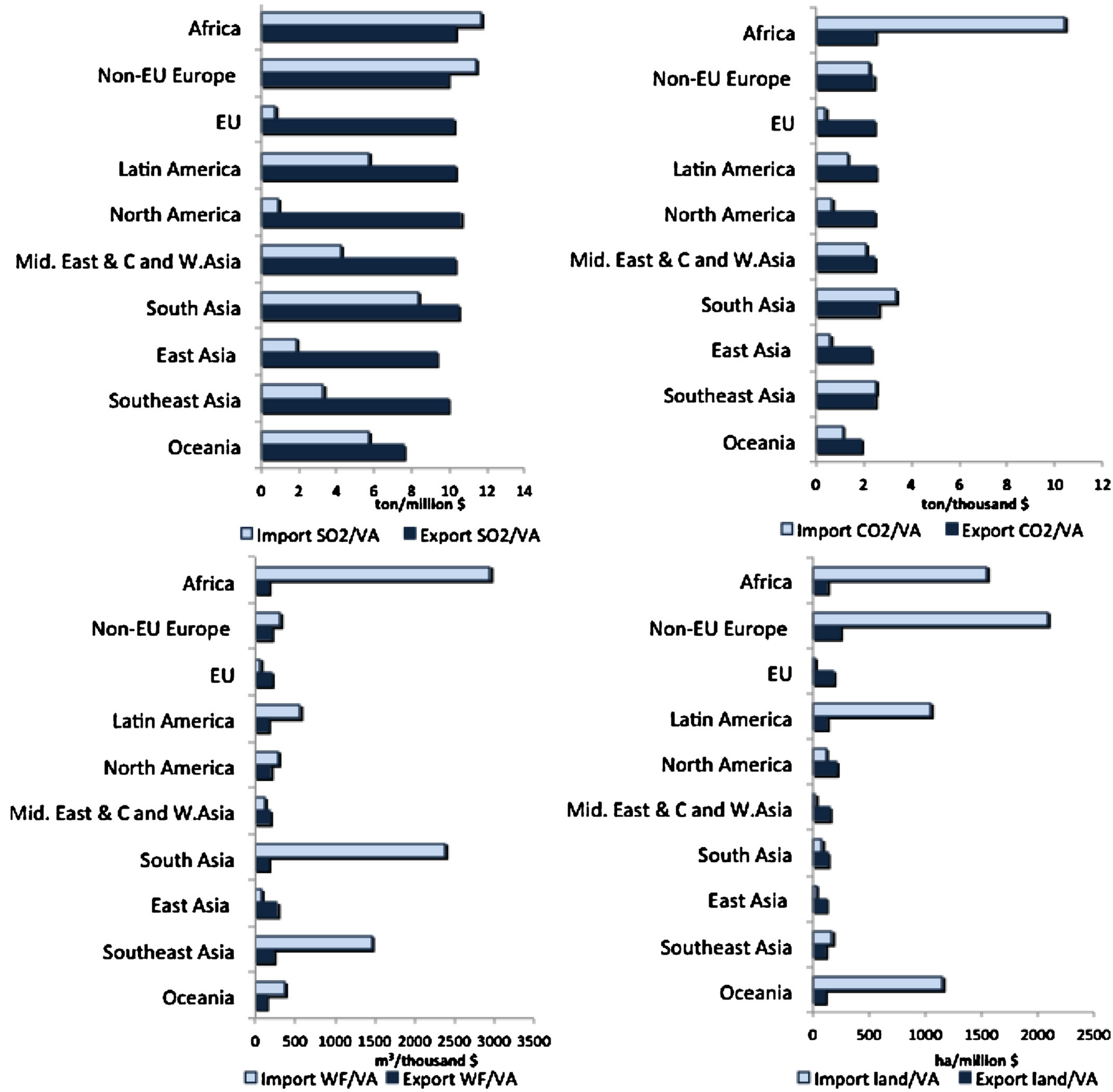

Fig. A.1. (a–d) SO_2, CO_2, water and land per unit of value added associated with China's exports and imports. *Note*: Middle East & Central and West Asia is Middle East & Central and West Asia. *Note*: for illustrative purpose, 26 sectors from MRIO analysis are aggregated into 12 sectors.

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