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Virtual Greenhouse Gas and Water Footprints Reduction: Emissions, Effluents and Water Flows Embodied in International Trade

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In the globalised world the greenhouse gas emission and water consumption are becoming increasingly important indicators for policy and decision making. Development of footprint assessment techniques over the last decade has provided a set of tools for monitoring CO_2 emissions, effluents and water flows in the world. An overview of the virtual CO_2 and virtual water flow trends in the international trade based on consumption perspective is performed. Review of the recent presented results indicates that: (1) They are significant CO_2 gaps between producer's and consumer's emissions, and US and EU have high absolute net imports CO_2 budget. (2) Asian countries have very sizable and growing population and have started to develop fast. Among top ten most populous countries in the world are China, India, United States, Indonesia, Brazil, Pakistan, Nigeria, Bangladesh, Russian Federation (partly Asian), Japan. Malaysia has also substantial population growth. Their impact on the environment as well as on the global footprint virtual trade of Asian is substantial and growing. (3) Namely China is a leading exporting country and increasingly carries a load of GHG emission, effluents and virtual water export that are triggered due to consumption in other importing countries. (4) By imported products that are produced with lower carbon emission intensity and less water consumption then in the domestic industry, international trade can reduce global environmental pressure.

1. Introduction

Between 1980 and 2016, total world population grew from 4,400 million to 7,400 million. By 2030, it is estimated that at least another billion people will be added for a total of more than 8,500 million, according to the demographic projections of the Population Reference Bureau (PRB, 2016). Responding to the needs of a rapidly growing population can challenge a country's ability to manage its natural resources on a sustainable basis. Rapid population growth rates can make it difficult for countries to raise standards of living and protect the environment, because the more people there are, the greater the need for food, health care, education, houses, land, jobs, and energy. Asian countries have very sizable and growing population and have started to develop fast. In 2016, the population of Asia is 4,400 million, which is take around 59 % of global population (PRB, 2016). As seen in Figure 1, among top ten most populous countries in the world are China, India, United States, Indonesia, Brazil, Pakistan, Nigeria, Bangladesh, Russian Federation (partly Asian), Japan (Internet World Stats, 2016). Malaysia has also substantial population growth. Besides the population increase, the economic and international trade both have been developing very fast in recent decades. As shown in Figure 2, the world GDP in 2015 is more than 2 fold of 2000 in current US$ value. Global trade as well develop significantly. Merchandise trade in the world was 3.8 x 10^{13} US$ in 2014, which is take around of 45 % of Global GDP (after The World Bank, 2016). Trade is the sum of exports and imports of goods and services, which measured as a share of Gross Domestic Product. In 2015, the global trade take of 57.9 % of world GDP, and the merchandise take of 45 % of the world GDP. Population increasing and international trade developing means that the food, wealth, environment, energy source must be distributed among more people globally. Their impact on the environment as well as on the global footprint virtual trade is substantial and growing.

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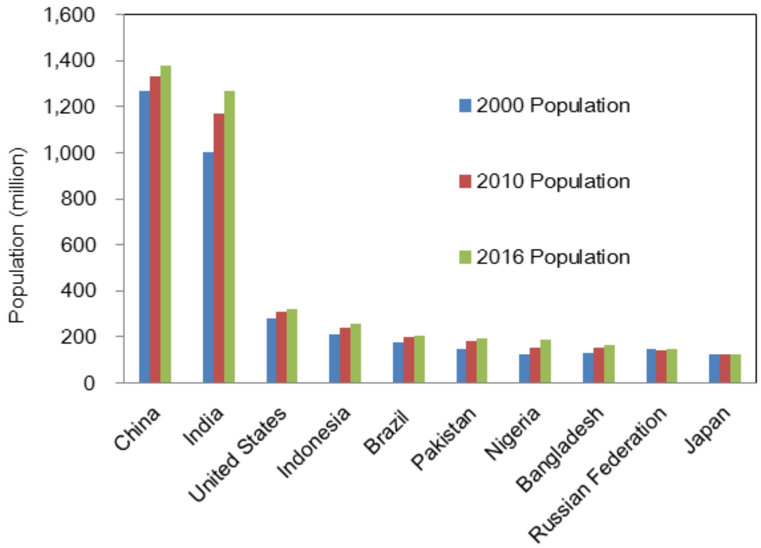

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Figure 1: Top ten countries with high population in the world (Internet World Stats, 2016)

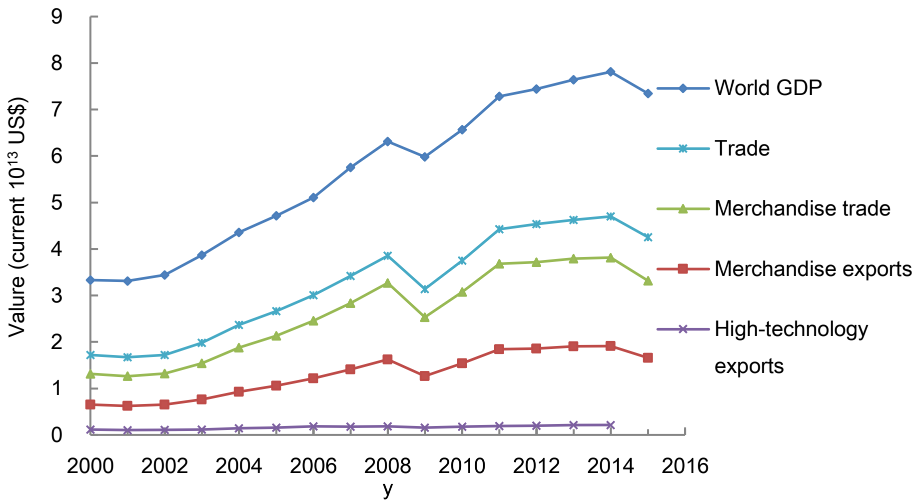

Figure 2: The world GDP and global trade from 2000-2015 (after The World Bank, 2016a)

Table 1: Leading exporters and importers in world merchandise trade in 2015 (WTO, 2016)

Exporters	Rank	Value (x 10^9 US$)	Share (%)	Importers	Rank	Value (x 10^9 US$)	Share (%)
China	1	2,275	17.4	United States	1	2,308	17.3
EU(28) exporters	2	1,985	15.2	EU	2	1,914	14.4
United States	3	1,505	11.5	China	3	1,682	12.6
Japan	4	625	4.8	Japan	4	648	4.9
Korea	5	527	4.0	Hong Kong China	5	559	4.2
Hong Kong China	6	511	3.9	Korea	6	436	3.3
Canada	7	408	3.1	Canada	7	36	3.3
Mexica	8	381	2.9	Mexico	8	405	3.0
Singapore	9	351	2.7	India	9	392	2.9
Russian Federation	10	340	2.6	Singapore	10	297	2.2

Table 1 shows the leading exporters and importers in world merchandise trade in year 2015. It can be seen that China is the top exporter, estimated 17.4 % of all export value. United States and EU28 (in the future E27) are top two main importers which are around 31.7 % of global importer value.

2. Carbon emissions embodied in the global trade

Beside a very considerable effort in many countries, see e.g. Mohd Nawi at al. (2016) and also developing countries, see e.g. Gholamzadeh Chofreh et al. (2016) there was globally a 60 % increase in annual carbon emissions between 1992 and 2013 (PRB, 2016). Fast expanding Chinese economy posted the largest increase by volume over this period, which was also the largest amount in year 2013.

Carbon footprint accounting has been proved to be a good approach to indicate the total carbon emissions of a person, a sector, a region and a nation. Carbon emissions growth is usually reported on a territorial basis not accounting for the international trade. However, the products consumed in many countries increasingly rely on coal, oil and gas extracted and burned in those countries where CO_2 emissions are not so tightly regulated (Liu et al., 2015). Since the total amount of carbon dioxide is not only dependent upon the direct emitters but also indirectly through the emitters supply chain, this concept of 'consumption-base' emission can help us identify the "embodied carbon emissions" in the in the trade.

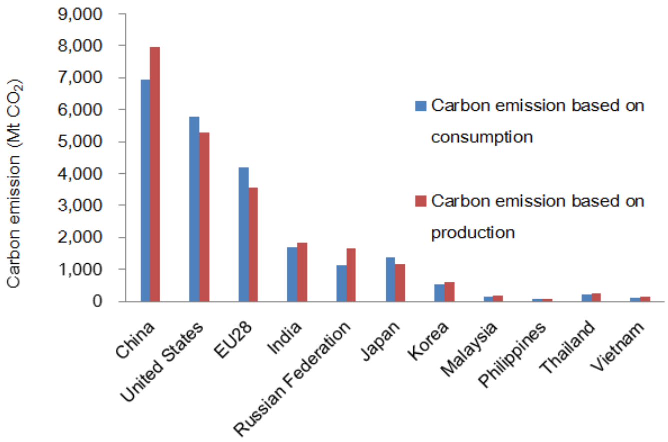

Figure 3: The CO_2 in 2011 based on the production-based and consumption-based principle (after OECD, 2016)

Figure 3 shows the difference between the CO_2 emissions in a region, which are based on the production and consumption principles in the year 2011 (after OECD, 2016). Considering the production-based CO_2 emission, China is the biggest CO_2 emissions producer, emitting about 2,670 Mt of CO_2 more than the US. However, based the consumption-based CO_2 emissions, the difference of China and US decreases to 1,176 Mt. China, India, Russian Federation and Malaysia all have lower consumption-based carbon emissions compared with the production-based carbon emission. The US and EU have high absolute net imports CO_2 budget.

Table 2: Net-exports of CO_2 emissions in 1995-2011 in Mt (OECD, 2016)

Year	1995	2000	2003	2005	2007	2009	2011
China	316.545	331.367	481.557	953.286	1,236.993	870.973	995.696
Russian Federation	521.621	827.077	703.980	646.690	492.685	484.378	531.829
India	43.406	77.208	74.768	75.146	87.724	126.897	134.501
Korea	-10.992	26.048	17.665	-1.321	-15.968	50.776	61.646
Malaysia	-1.882	22.008	26.114	44.004	43.546	42.991	39.131
US	-155.680	-529.405	-627.710	-770.142	-664.214	-484.364	-498.239
EU28	-421.762	-690.749	-705.026	-765.194	-825.869	-681.132	-661.506
Japan	-252.787	-222.058	-178.710	-199.328	-141.389	-150.113	-187.777
Turkey	-21.841	-30.584	-24.996	-54.509	-61.440	-37.095	-64.496

Table 2 shown that the emissions embodied in a country's international trade measured have been increasing over time. The net-exports of carbon emission in China have reached 995.696 Mt in 2011 which is more than 3 times in 1995. EU28 and United State are in net-imports of carbon emission, which reached 498 Mt and 661 Mt in 2011. The embodied carbon emissions from the production of traded goods and services have overall increased from 4.3 Gt CO_2 in 1990 to 7.8 Gt CO_2 in 2008 (Peters et al., 2011).

3. Water embodied in the global trade

The global trade in goods has allowed countries with limited water resources could rely on the water resources in other countries to meet their needs. As agriculture products and industrial products are traded internationally, meanwhile the water footprint follows in the form of virtual water. China participated in world trade positively and made a great contribution to global water resources allocation. During 1996 – 2005, the virtual water that China exported to the world accounted for 11 % of global exported virtual water flows (Mekonnen and Hoekstra, 2011). In 2013, the virtual water that China exported to the world was 23.73 Gm^3 (Zhang et al., 2016), 72 % green water, 7 % blue water, and 21 % gray water. The main exported virtual water was from crop products. Table 3 shows the virtual water embedded in the top ten agricultural products in China exports. Green water was the most important water resource in China's agricultural production and also has an irreplaceable role in maintaining the production and service function of earth's land ecosystem.

Table 3: Virtual water embodied in top ten agricultural products in China exports (Zhang et al., 2016)

Agricultural products	Virtual water (Gm^3/y)	Percent (%)	Green water (m^3/t)	Blue water (m^3/t)	Grey water (m^3/t)
Maize	4.81	16	791	74	255
Kidney beans & white beans	1.67	6	1,896	0	804
Green tea in packages exceeding 3 kg	1.56	5	9,277	798	1,496
Rice	1.37	5	79	355	310
Green tea in packages not exceeding 3 kg	1.21	4	9,277	355	310
Wheat nes and meslin	0.96	3	821	466	311
Apple	0.96	3	796	30	284
Soya beans	0.82	3	2,549	249	218
Garlic	0.70	2	306	11	196
Swine cuts	0.68	2	5,050	405	648

Similarly with the virtual carbon emissions flows, the water flows situation has also been developing as well. During 1995 - 2008, global water use grew by 37.3 % (Arto et al., 2016). China, India and Brazil contributing most to the global water increase Figure 4 shows the largest inter-regional virtual water trade fluxes. In terms of international trade, the EU28 was the largest water importer, and China the main water exporters.

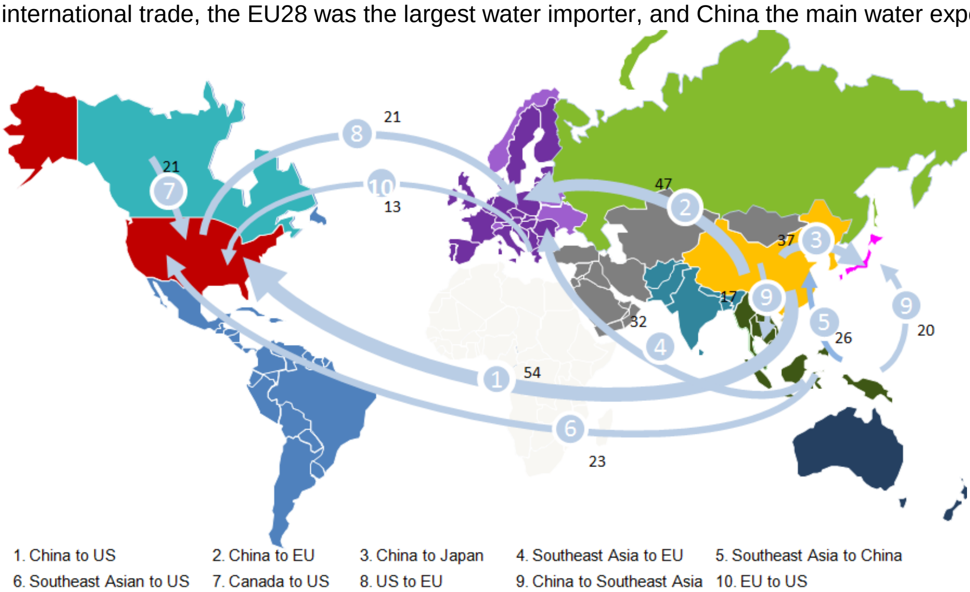

Figure 4: Ten largest inter-regional virtual water trade fluxes in Gm^3/y (Liu et al., 2016)

4. Discussion

With the developing of international trade, many developing countries are increasing the share of manufactured goods in their exports, including exports to developed countries. The most dynamic categories of their manufactured exports are labor-intensive, low-knowledge products, like clothes, carpets, crude steel, and some manually assembled products. By contrast, developing countries imports from developed countries are mostly capital - and knowledge-intensive manufactured goods - primarily machinery and transport equipment - in which developed countries retain their comparative advantage. Moreover, carbon emissions leakage that carbon emissions embodied in importing to other countries for product consumption from developing countries are highly related to the differences of technological level.

One measure of science and technology is GERD - gross domestic expenditure on R&D (OECD, 2016). The indicator provided is that expenditures for research and development are current and capital expenditures (both public and private) on creative work undertaken systematically to increase knowledge, including knowledge of humanity, culture, and society, and the use of knowledge for new applications.

Figure 5 shown the GERD value of high population country in Asia. The developed country Japan and Korea are in high GERD value, and most developing country including China are in relative lower GERD value.

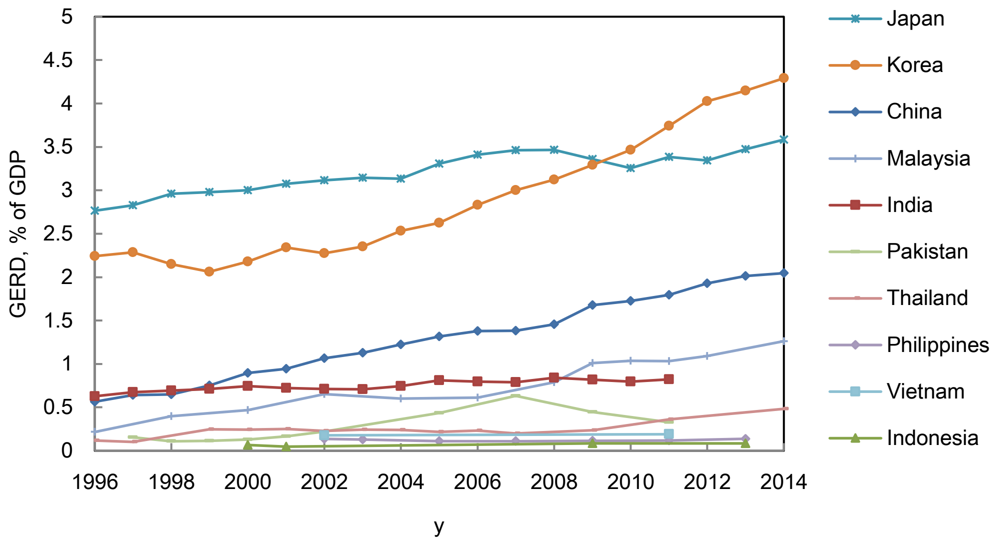

Figure 5: GERD value of seven countries with high population in the Asia (after The World Bank, 2016b)

Consequently, the national carbon emission trade scheme provides an effective way to reduce carbon emissions leakage.

5. Conclusions

Embodied carbon flows and water flows analyses have been important for the evaluation of the current condition of virtual carbon emissions (carbon footprints or better GHG footprints) and virtual water trade (water footprint) on global scale of the world, and identify the main sectors in embodied emission flows among different regions. Previous works have not fully stipulated this importance (Lam et al., 20111).

A future direction should be focused into two main areas:

(i) To work towards the self-sufficient regions based on more efficient processes by combining production of surrounding countries in the region to reduce substantial environmental impact for transport.

(ii) To develop the shared mechanism and market share of virtual emissions, effluents and virtual water between trading partners regionally and internationally.

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