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RESEARCH ARTICLE

Global network of embodied water flow by systems input-output simulation

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Abstract The global water resources network is simulated in the present work for the latest target year with statistical data available and with the most detailed data disaggregation. A top-down approach of systems input-output simulation is employed to track the embodied water flows associated with economic flows for the globalized economy in 2004. The numerical simulation provides a database of embodied water intensities for all economic commodities from 4928 producers, based on which the differences between direct and indirect water using efficiencies at the global scale are discussed. The direct and embodied water uses are analyzed at continental level. Besides, the commodity demand in terms of monetary expenditure and the water demand in terms of embodied water use are compared for the world as well as for three major water using regions, i.e., India, China, and the United States. Results show that food product contributes to a significant fraction for water demand, despite the value varies significantly with respect to the economic status of region.

Keywords embodied flow, international trade, water resources, world economy

1 Introduction

With reference to the embodiment perspective of systems ecology (Odum, 1971; 1983; 1994), the concept of embodied water (or virtual water) can be defined as the total water required to generate a product or service. Associated with the globalized economic connection, there is a commonly overlooked water resources network in terms of embodied water flow. Especially, the international embodied water flow along with the separation between production and consumption makes the difference between water withdrawal (direct water use) and water demand (embodied water use) salient for regional water budget. As such, understanding the global embodied water network is of significant implication to the policy makers concerning water management policies to make the best allocation of water resources.

During the past decades, a number of studies have been carried out to investigate the embodied water network of the world, most of which focus on the water resources embodied in food since about three quarters of water resources are used by food production processes directly (World Bank, 2011). The global embodied water flows associated with international crop trade in the period 1995–1999 were analyzed by Hoekstra and Hung (2002; 2005). Fraiture et al. (2004) investigated the water flows embodied in cereal during the period 1981–2000 and analyzed how those flows influence global water use. The embodied water contents of crop and stock products in 2000 were calculated by Oki and Kanae (2004), based on which the comparative advantages in terms of water using efficiency of different countries were analyzed. Afterward, Yang et al. (2006) assessed the embodied water using efficiency associated with international food trade at both global and national levels during 1997–2001. Besides the above studies focusing on food products, embodied water use associated non-food products was also tentatively analyzed in Hoekstra and Chapagain (2006) on the basis of previous literature (Chapagain and Hoekstra, 2003; Hoekstra and Hung, 2002; 2005).

It is worth noticing that all the aforementioned studies are based on a bottom-up framework which collects dispersive details (e.g., embodied water intensity or content of specific commodity) and aggregates them into

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global and international water profiles. The most attractive merit of the bottom-up approach is that it provides information about our daily necessities which can be connected with our lives intuitively, e.g., embodied water content of paddy rice, wheat, beef, and even T-shirt are identified separately in Hoekstra and Chapagian (2006). However, the diversity of commodities makes it impossible to cover all economic outputs in a consistent basis, which makes the combined uncertainties a critical issue for global level accounting (Chen, 2011; Yang et al., 2006).

On the contrary, the top-down approach, which distributes total water use into economic flows based on a systems network model, can be applied to cover all the commodities based on a unified basis for macro-scale accounting (Wiedmann et al., 2007; Hertwich and Peters, 2009; Wiedemann, 2009; Peters, 2010). By virtue of the economic input-output (I/O) table which illustrates the intra- and international trading network explicitly, I/O simulation has become one of the most prevalent top-down approaches during recent years (e.g., Duarte et al., 2002; Velázquez, 2006; Guan and Hubacek, 2007; Hubacek et al., 2009; Yu et al., 2010; Zhao et al., 2009, 2010). Especially, originated from the system ecological perspective to treat water as an ecological endowment parallel to energy and greenhouse gas, the approach of systems I/O simulation was brought forward, and it has been applied to analyze the embodied water uses of different macro-scale economies (Cai, 2010; Chen, 2011; Chen et al., 2010a; Chen and Chen, 2010a; 2011; Zhou et al., 2010).

In the light of previous studies, this research carries out a systems I/O simulation for the global network of water resources for the latest target year with statistical data available (2004) and with the most detailed data disaggregation (112 regions and 44 sectors for each region). Based on the numerical simulation, the embodied water intensities of all economic commodities from 4928 producers (each sector from each region is considered as a separate producer) are calculated. Then the embodied water intensities for the 44 sectors on global average are analyzed to show the embodied water compositions and sectoral differences. Besides, the direct and embodied water uses at continental scales are investigated. And last, the commodity demand in terms of monetary expenditure and the water demand in terms of embodied water use are compared for the world as well as for three major water using regions, i.e., India, China, and the United States.

2 Methodology

By virtue of the available economic statistics and resources accounts, systems I/O table can be compiled to reveal the economic and environmental activities within the concerned system boundary. A schematic systems I/O table for the world divided into r regions with n_i sectors for the i-th region (i = 1 to r) regarding embodied water simulation is illustrated in Table 1.

The presented systems I/O table consists of three major parts: Part I illustrating direct water uses for all productive and consumptive purposes, Part II illustrating commodities input and output during intermediate production processes, and Part III illustrating the final demand of commodities. To distinguish the same sectors from different regions (e.g., the Agriculture sectors from India and from the United States) as separate units in the simulation, Sector h from Region m is denoted as Producer i ($i = h + \sum_{k=1}^{m-1} n_k$) in this study. Thereafter the physical balance of embodied water flows for a specific producer can be portrayed as Fig. 1, according to which Producer i links with the environment and economy via inputting direct water resources through withdrawing from water sources (i.e., w_i), inputting embodied water resources through

Table 1 Schematic multi-region systems I/O table associated with water resources (revised according to Chen, 2011)

From/To			Commodity and water									
			Intermediate use							Final demand		
			Region 1			…	Region r			Region 1	…	Region r
			Sector 1	…	Sector n_1		Sector 1	…	Sector n_r			
		Sector 1										
	Region 1	…										
		Sector n_1										
Commodity	…					Part II					Part III	
		Sector 1										
	Region r	…										
		Sector n_r										
Water								Part I				

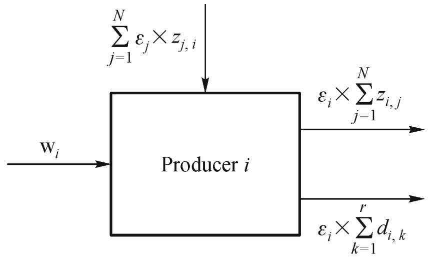

Fig. 1 Physical balance of embodied water flows for Producer i (revised according to Chen, 2011)

purchasing commodities (i.e., $\sum_{j=1}^{N} \varepsilon_j \times z_{j,i}$ in which N denotes total producer number $\sum_{k=1}^{r} n_k$, ε_j denotes embodied water intensity of output from Producer j, and $z_{j,i}$ denotes the intermediate input from Producer j), and outputting embodied water resources through selling commodities (i.e., $\varepsilon_i \times \sum_{j=1}^{N} z_{i.j}$ and $\varepsilon_i \times \sum_{k=1}^{r} d_{i,k}$, in which $d_{i,k}$ denotes output to Region k for final demand).

The embodied water balance for Producer i can be formulated as

$$w_i + \sum_{j=1}^{N} \varepsilon_j \times z_{j,i} = \varepsilon_i \times \left(\sum_{j=1}^{N} z_{j,i} + \sum_{k=1}^{r} d_{i,k} \right). \quad (1)$$

For all the N producers of the whole simulated system, we have

$$\begin{cases} w_1 + \sum_{j=1}^{N} \varepsilon_j \times z_{j,1} = \varepsilon_1 \times \left(\sum_{j=1}^{N} z_{j,1} + \sum_{k=1}^{r} d_{1,k} \right), \\ w_2 + \sum_{j=1}^{N} \varepsilon_j \times z_{j,2} = \varepsilon_2 \times \left(\sum_{j=1}^{N} z_{j,2} + \sum_{k=1}^{r} d_{2,k} \right), \\ \vdots \\ w_N + \sum_{j=1}^{N} \varepsilon_j \times z_{j,N} = \varepsilon_N \times \left(\sum_{j=1}^{N} z_{j,N} + \sum_{k=1}^{r} d_{N,k} \right). \end{cases} \quad (2)$$

Denote

$$\boldsymbol{E} = \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \vdots \\ \varepsilon_N \end{bmatrix},$$

$$\boldsymbol{W} = \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_N \end{bmatrix},$$

$$\boldsymbol{X} = \begin{bmatrix} z_{1,1} & z_{2,1} & \cdots & z_{N,1} \\ z_{1,2} & z_{2,2} & \cdots & z_{N,2} \\ \vdots & \vdots & & \vdots \\ z_{1,N} & z_{2,N} & \cdots & z_{N,N} \end{bmatrix},$$

and

$$\boldsymbol{Y} = \begin{bmatrix} \sum_{j=1}^{N} z_{1,j} + \sum_{k=1}^{r} d_{1,k} & 0 & \cdots & 0 \\ 0 & \sum_{j=1}^{N} z_{2,j} + \sum_{k=1}^{r} d_{2,k} & \cdots & 0 \\ \vdots & \vdots & & \vdots \\ 0 & 0 & \cdots & \sum_{j=1}^{N} z_{N,j} + \sum_{k=1}^{r} d_{N,k} \end{bmatrix}.$$

A matrix formula can be presented as

$$\boldsymbol{W} + \boldsymbol{X} \times \boldsymbol{E} = \boldsymbol{Y} \times \boldsymbol{E}. \quad (3)$$

Given the condition ***Y*–*X*** is reversible, which is guaranteed by construction method for economic I/O table (Miller and Blair, 2009), Eq. (3) can be solved to obtain vector ***E*** as

$$\boldsymbol{E} = (\boldsymbol{Y} - \boldsymbol{X})^{-1} \times \boldsymbol{W}. \quad (4)$$

Thereafter for any given set of commodities

$$\boldsymbol{C} = \begin{bmatrix} c_1 \\ c_2 \\ \vdots \\ c_N \end{bmatrix},$$

where c_i indicates the output of Producer i contained in the commodities set, the corresponding embodied water use can be calculated as

$$\boldsymbol{R} = \boldsymbol{E} \times \boldsymbol{C}. \quad (5)$$

To separate the direct and indirect water using efficiencies for Producer i, the embodied water intensity can be decomposed as

$$\varepsilon_i = \varepsilon_i^a + \varepsilon_i^b, \tag{6}$$

where $\varepsilon_i^a = w_i / \left(\sum_{j=1}^{N} z_{j,i} + \sum_{k=1}^{r} d_{i,k}\right)$ indicates the direct water intensity and $\varepsilon_i^b = \varepsilon_i - \varepsilon_i^a$ indicates the indirect water intensity. Therefore

$$\boldsymbol{E} = \boldsymbol{E}^a + \boldsymbol{E}^b, \tag{7}$$

and

$$\boldsymbol{R} = \boldsymbol{R}^a + \boldsymbol{R}^b, \tag{8}$$

where $\boldsymbol{E}^a = \boldsymbol{Y}^{-1} \times \boldsymbol{W}$, $\boldsymbol{E}^b = [(\boldsymbol{Y} - \boldsymbol{X})^{-1} - \boldsymbol{Y}^{-1}] \times \boldsymbol{W}$, $\boldsymbol{R}^a = \boldsymbol{Y}^{-1} \times \boldsymbol{W} \times \boldsymbol{C}$, and $\boldsymbol{R}^b = [(\boldsymbol{Y} - \boldsymbol{X})^{-1} - \boldsymbol{Y}^{-1}] \times \boldsymbol{W} \times \boldsymbol{C}$ indicate the direct water intensity vector, indirect water intensity vector, direct water use, and indirect water use, respectively.

3 Data sources

This study adopts the Global Trade Analysis Project (GTAP) Database Version 7 Interim Release 2 (Narayanan and Walmsley, 2008) to compile the economic data (Part II and Part III in Table 1) for the global systems I/O table of 2004. The original GTAP database includes 112 nation-scale regions (94 national/sub-national regions and 18 supra-national regions) and identifies 57 sectors (14 agriculture sectors, 32 industry sectors, and 11 service sectors) for each region (see Appendix for detailed information). In the present study, the 14 agriculture sectors of each region are aggregated into one in order to avoid the uncertainties introduced by the manipulation carried out during GTAP data preparation (Peters, 2007; Narayanan and Walmsley, 2008). Consequently, the compiled global systems I/O table includes 44 sectors (see Appendix) for 112 regions and thus has 4928 producers altogether.

This study accounts for only fresh water withdrawal when direct rainwater use (e.g., rainfall irrigation) is not included. The regional fresh water withdrawal divided into agricultural, industrial, and other categories is calculated based on the World Development Indicators database (World Bank, 2011). Further, to obtain the direct water use of each producer and each final demand item (Part I in Table 1), the domestic agricultural/industrial water withdrawal is allocated to domestic agriculture/industry producers while the domestic other water withdrawal is allocated to domestic service producers, domestic consumers (final demand), and foreign producers (export) according to their respective purchases from domestic Water Collection, Purification, and Distribution sector. It should be noticed that the term water use has slightly different meanings in this study comparing to in previous studies. Previous studies usually refer to water consumption without counting in the return flow (the irrigated water that returns to the surface or ground water aquifer, thus can be reused again). But this study, via applying the water withdrawal data, the return flow is taken into account as part of the water use. Recognizing this minor difference, the embodied water use by a region is defined as water demand in this study, instead of water consumption in previous studies, to avoid misleading the readers. More detailed procedures to construct the systems I/O table, including the application of the GTAP database and the allocation of resources between sectors, can be referred to the literature (e.g., Miller and Blair, 2009; Davis and Caldeira, 2010) and thus are not explained here.

4 Results and discussion

The embodied water intensities of all economic commodities from the 4928 producers are calculated (see Supplemental information) based on data extracted from the global systems I/O table associated with water resources compiled in this study. Generally the comparison between direct and indirect water intensities is of concern to reveal the composition of water using efficiency (Zhao et al., 2010). Presented in Fig. 2 are the embodied water intensities decomposed into direct and indirect components of the 44 sectors at the global scale.

According to Fig. 2, the agriculture related sectors and the Water Collection, Purification, and Distribution sector have relatively very high embodied water intensities, and the manufacture sectors generally have median intensities, while most services sectors have very low intensities. Regarding the compositions, only 4 (i.e., Agriculture; Electricity; Gas Manufacture and Distribution; and Water Collection, Purification, and Distribution) among the 44 sectors rely more on direct than indirect water uses, while all the other 40 sectors show higher indirect than direct water intensities. Generally, sectors with high direct water intensities have high potentials to save water resources through improving direct water using technology (e.g., improving irrigation efficiency), while those with high indirect water intensities might be easier to save water resources through improving indirect water using technology (e.g., reducing material input). According to the results, identifying the direct and indirect water intensities separately is of significant implementations, especially for those sectors with considerable differences between these two indicators. For example, if the direct water using efficiency for the Processed Rice sector is improved by 1% (1% less water input is used to produce the same amount of output), only 128 m^3 of water resources can be saved for each million dollars of output generated by this sector; however, if the indirect water

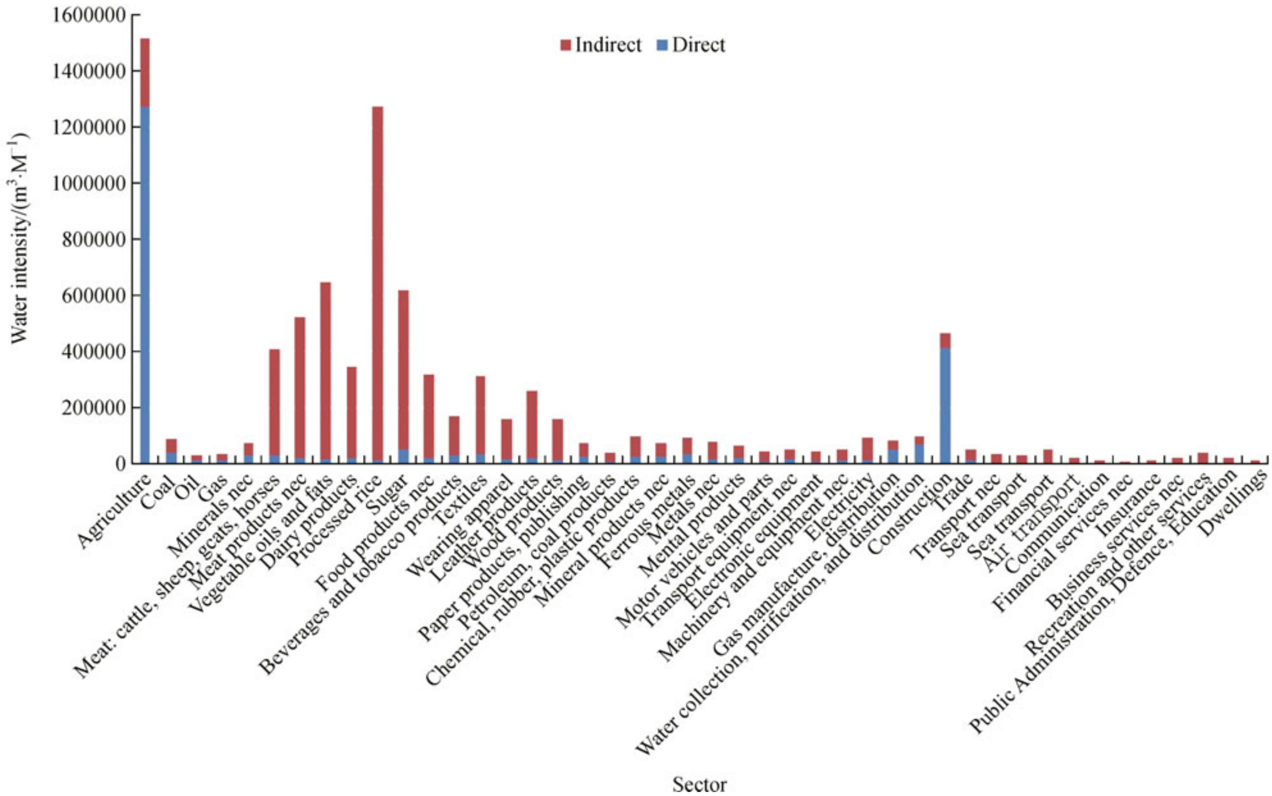

Fig. 2 Embodied water intensities of the 44 sectors at the global scale

using technology is improved by 1% (1% less non-water input is used to produce the same amount of output), about 12593 m^3 of water resources can be saved for the same amount of output.

The direct and embodied water uses for the world and different continents are presented in Table 2, in which the embodied water uses are divided into activities as well as into product categories (see Appendix for classification). About 56% of the embodied water use of the world can be attributed to the Asian nations, which, however, contain 61% of the global population. Meanwhile, 81% of water resources are consumed by household at the global level while the fractions for continents do not vary significantly (between 74% and 87%). Water embodied in investment goods sums up to 13% of global water demand, which is much smaller than the corresponding fractions for global energy input (19% according to Chen and Chen, 2011b) and for global carbon dioxide emission (21% according to Chen et al., 2010b). While Processed Food contributes to similar fractions of embodied water use for different continents, the fractions for Agricultural Products range between 13% for North America and 49% for Africa. Meanwhile, the water resources embodied in Non-food Products account for over 60% of water demand for

Table 2 Direct and embodied water uses at continental and global levels

Region	Direct water use /(Gm^3)	Embodied water use/(Gm^3)	Contributions of activities			Contributions of commodities		
			Household Consumption	Government Consumption	Investment	Agricultural Product	Processed Food	Non-food Product
Africa	261	254	87%	5%	8%	49%	23%	27%
Asia	2461	2248	84%	5%	11%	47%	22%	31%
Europe	464	660	76%	8%	16%	17%	21%	63%
North America	635	706	74%	6%	20%	13%	21%	65%
Oceania	29	31	76%	7%	18%	18%	21%	60%
South America	165	115	84%	7%	10%	20%	28%	53%
World	4014	4014	81%	6%	13%	35%	22%	43%

Note: fractions might not be summed up to total due to rounding

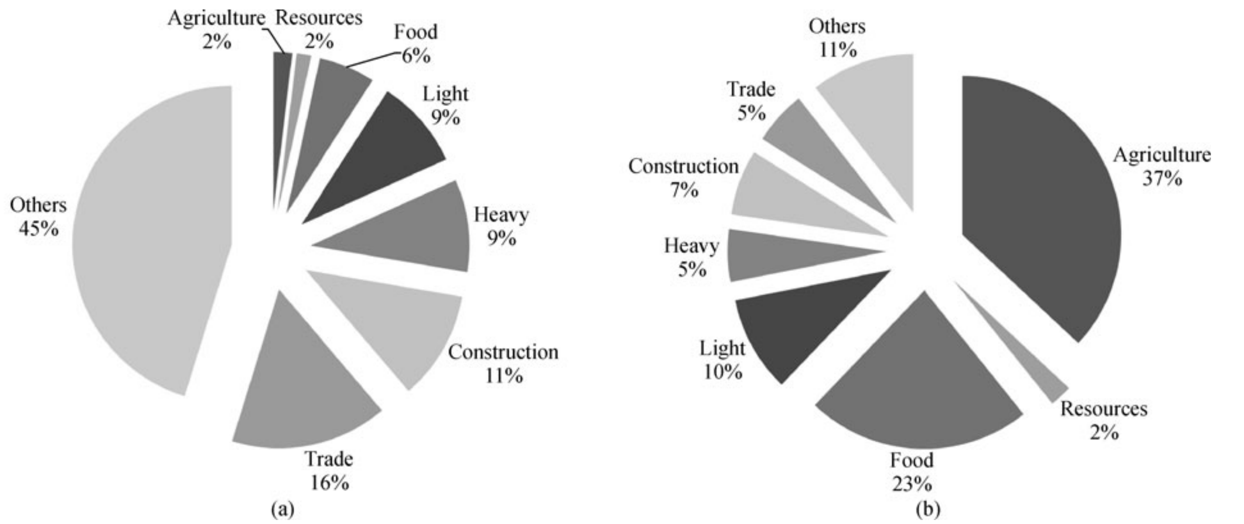

Fig. 3 Demand patterns of the world: (a) monetary expenditure; (b) embodied water use (in this and the following figures, “Agriculture” stands for “Agricultural Product,” “Resources” stands for “Mining, Extraction, and Utility,” “Food” stands for “Processed Food,” “Light” stands for “Other Light Manufacture,” “Heavy” stands for “Other Heavy Manufacture,” “Trade” stands for “Trade, Transportation, and Communications,” “Others” stands for “Other Services”; direct water use for final demand is omitted for embodied water use account)

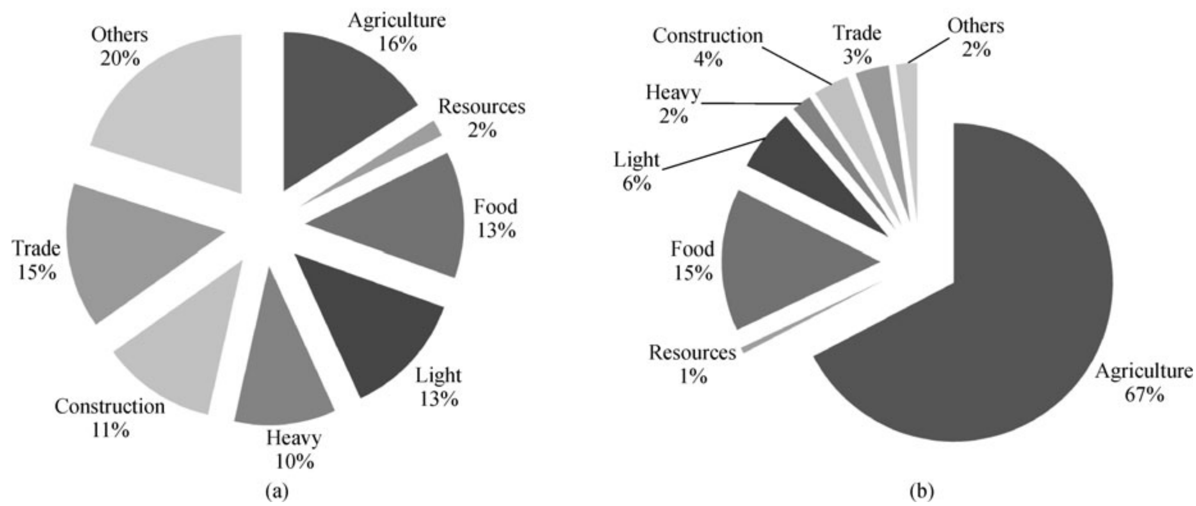

Fig. 4 Demand patterns of India: (a) monetary expenditure; (b) embodied water use

Europe, North America, and Oceania but only about 30% for Africa and Asia, reflecting their different demand patterns.

Illustrated in Figs. 3 to 6 are the comparisons between commodity demand in terms of monetary expenditure and water demand in terms of embodied water use for the world and the three largest direct water using regions (i.e., India, China, and the United States), in which all commodities are classified into eight categories (i.e., Agricultural Product; Processed Food; Mining, Extraction, and Utility; Other Light Manufacture; Other Heavy Manufacture; Construction; Trade, Transportation, and Communication; and Other Services; see Appendix for classifications and abbreviations).

The comparisons show significant distinction between commodity demand pattern and water demand pattern for the world as well as for the regional economies. According to Fig. 3, the category of Other Services provides the largest share (45%) for commodity demand of the world, followed by Trade, Transportation, and Communication (16%) and Construction (11%). On the other side, despite of their very small shares in terms of monetary expenditure, Agricultural Product appears as the largest embodied water using source (37%) and Processed Food also makes considerable contribution (23%) to the global water demand. At regional scale, Agricultural Product

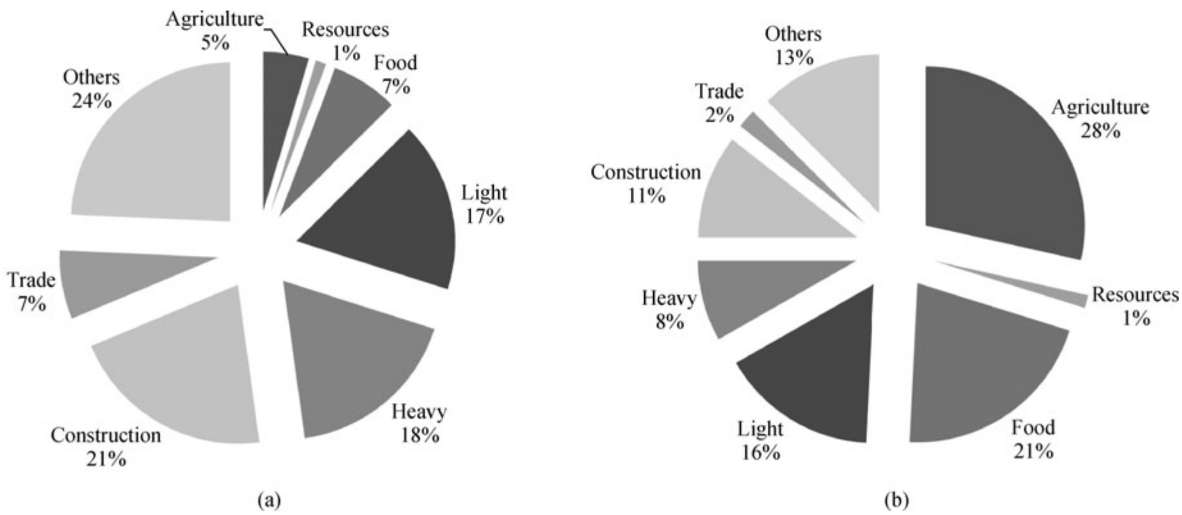

Fig. 5 Demand patterns of China: (a) monetary expenditure; (b) embodied water use

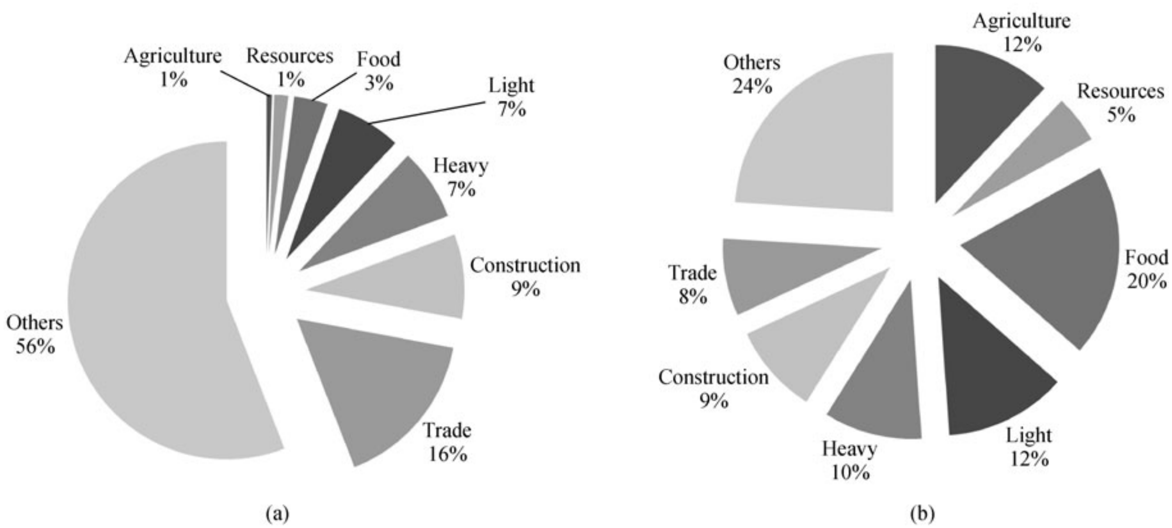

Fig. 6 Demand patterns of the United States: (a) monetary expenditure; (b) embodied water use

contributes the second largest fraction (16%) to commodity demand in India, but offers over two-thirds (67%) of the water demand. Taking Processed Food (17%) into account, over 80% of the water demand in India is driven by the demand of food products, which identifies the large population and the developing economic status of this country. As the second largest commodity source, the category of Construction contributes to 21% of monetary expenditure and 11% of embodied water use in China owing to the large amount of investment in infrastructure and building. Meanwhile, Agricultural Product (28%) and Processed Food (21%) contribute to about half of the embodied water use, which indicates that food demand is also a major driving force for water demand in this developing economy. For the United States, 56% of monetary expenditure and 24% of embodied water use are attributed to the category of Other Services, both ranking the first places in respective patterns. However, differing from the world as well as India and China, the United States has only 12% of its water demand attributed to Agricultural Product, which is even much lower than the fraction attributed to Processed Food (20%).

5 Conclusions

Along with the separation between production and consumption and the uneven geological distribution of water resources, the water network in terms of embodied water flow is playing an important role to balance the local, national, and global water budgets. As such, a comprehensive global profile of the embodied water network is of concern to reflect the substantial resource endowments with significant implications for water management policies at different scales. Therefore, this study simulates the global water resources network in 2004 via employing a systems I/O simulation using data extracted from the GTAP and the World Bank data sets.

The embodied water intensities indicating the embodied water content per unit of output are calculated for all the economic commodities classified into outputs from 4928 producers. Meanwhile, the global average direct water intensities for the 44 accounted sectors are compared with the indirect water intensities. Generally, the direct water intensity implies the water saving potential associated with water using process (i.e., water input) while the indirect one is connected with the non-water using process (i.e., all intermediate inputs except water input). In other words, sectors with high direct water intensities have high potential to save water resources through improving water using technology (e.g., improving irrigation efficiency in the Agriculture sector), while those with high indirect water intensities have high potential for water conservation through non-water using technology upgrade (e.g., reducing material input in the Processed Rice sector). Therefore, despite of the comparatively low direct water intensity, sector with high indirect water intensity may also contribute to water saving strategy significantly. From this perspective, the trade-off between direct and indirect water saving measures can be compared to guide not only direct but also indirect water regulation policies.

The embodied water uses at global and continental levels are analyzed via dividing the economic activities into Household Consumption, Government Consumption, and Investment and dividing the product categories into Agricultural Product, Processed Food, and Non-food Product. Household Consumption is the largest embodied water using activities for the world as well as for each continent. Regarding product categories, Agricultural Product dominates in Africa and Asia while Non-food Product contributes the largest fractions for Europe, North America, Oceania, and South America.

The water demand in terms of embodied water requirement shows very different pattern from the commodity demand in terms of monetary expenditure for the world as well as for regional economies. Despite the category of Other Service category contributes to 45% of monetary expenditure for the world, the corresponding embodied water use occupies only 11% of global water demand. On the contrary, the categories of Agricultural Product and Processed Food provide 37% and 23% of embodied water use with only 2% and 6% of monetary expenditures, respectively. Over two-thirds of embodied water use for India can be attributed to the demand of Agricultural Product, reflecting the over-loaded population and comparatively agriculture-dominated demand pattern of this country. With about half of the embodied water use driven by demand of food products, China has a similar water demand pattern as the world except that Construction plays a much more important role for this developing economy. For the United States, commodities from Other Service provide the largest fractions for both commodity and water demands. Meanwhile, the contribution of food products for water demand in the United States (30%) is only half of that of world average (60%), while its embodied water use from Processed Food (20%) even exceeds that from Agricultural Product (12%) by a large degree. The results suggest that demand of food in developed economy is more dependent on manufactured food than on raw products. Besides, it seems the Engel's law is also applicable for water demand: i.e., as people become richer, the proportion of water demand attributed to food falls.

The current study provides an embodied water intensity database for 4928 entries from 112 regional economies and provides a preliminary exploration on the differences between direct and embodied water uses as well as the differences between commodity demand and water demand. For more concrete policy implementations regarding national water regulation strategies, further research should be carried out to investigate the inter-regional embodied water flows as well as the accompanied water budgets.

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Vitae

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Appendix

Table A1 Region definitions in the GTAP database (according to Narayanan and Walmsley, 2008)

No.	Region	Description
1	Australia	Australia
2	New Zealand	New Zealand
3	Rest of Oceania	American Samoa, Cook Islands,Fiji, French Polynesia, Guam, Island of Wallis and Futuna, Kiribati, Marshall Islands, Micronesia, Federated States of Nauru, New Caledonia, Niue, Norfolk Island, Northern Mariana Islands, Palau, Papua New Guinea, Samoa, Solomon Islands, Tokelau, Tonga, Tuvalu, Vanuatu
4	the mainland of China	the mainland of China
5	Hong Kong SAR of China	Hong Kong SAR of China
6	Japan	Japan
7	R.O. Korea	R.O. Korea
8	Taiwan Province of China	Taiwan Province of China
9	Rest of East Asia	D. P. R. Korea; Mongolia; Macao SAR of China
10	Cambodia	Cambodia
11	Indonesia	Indonesia
12	Laos	Laos
13	Malaysia	Malaysia
14	Philippines	Philippines
15	Singapore	Singapore
16	Thailand	Thailand
17	Viet nam	Vietnam
18	Rest of Southeast Asia	Brunei Darussalam, Timor-Leste
19	Bangladesh	Bangladesh
20	India	India
21	Pakistan	Pakistan
22	Sri Lanka	Sri Lanka
23	Rest of South Asia	Afghanistan, Bhutan, Maldives, Nepal
24	Canada	Canada
25	United States	United States of America
26	Mexico	Mexico
27	Rest of North America	Bermuda, Greenland, Saint Pierre and Miquelon
28	Argentina	Argentina
29	Bolivia	Bolivia
30	Brazil	Brazil
31	Chile	Chile
32	Colombia	Colombia
33	Ecuador	Ecuador
34	Paraguay	Paraguay
35	Peru	Peru
36	Uruguay	Uruguay
37	Venezuela	Venezuela
38	Rest of South America	Falkland Islands (Malvinas), French Guiana, Guyana, Suriname
39	Costa Rica	Costa Rica
40	Guatemala	Guatemala

(*Continued*)

No.	Region	Description
41	Nicaragua	Nicaragua
42	Panama	Panama
43	Rest of Central America	Belize, El Salvador, Honduras, Anguilla
44	Caribbean	Antigua & Barbuda, Aruba, Bahamas, Barbados, Cayman Islands, Cuba, Dominica, Dominican Republic, Grenada, Guadeloupe, Haiti, Jamaica, Martinique, Montserrat, Netherlands Antilles, Puerto Rico, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Trinidad and Tobago, Turks and Caicos, Virgin Islands, British, Virgin Islands, US
45	Austria	Austria
46	Belgium	Belgium
47	Cyprus	Cyprus
48	Czech	Czech Republic
49	Denmark	Denmark
50	Estonia	Estonia
51	Finland	Finland
52	France	France
53	Germany	Germany
54	Greece	Greece
55	Hungary	Hungary
56	Ireland	Ireland
57	Italy	Italy
58	Latvia	Latvia
59	Lithuania	Lithuania
60	Luxembourg	Luxembourg
61	Malta	Malta
62	Netherlands	Netherlands
63	Poland	Poland
64	Portugal	Portugal
65	Slovakia	Slovakia
66	Slovenia	Slovenia
67	Spain	Spain
68	Sweden	Sweden
69	UK	UK
70	Switzerland	Switzerland
71	Norway	Norway
72	Rest of European Free Trade Association	Iceland, Liechtenstein
73	Albania	Albania
74	Bulgaria	Bulgaria
75	Belarus	Belarus
76	Croatia	Croatia
77	Romania	Romania
78	Russia	Russian Federation
79	Ukraine	Ukraine
80	Rest of Eastern Europe	Moldova,

(*Continued*)

No.	Region	Description
81	Rest of Europe	Andorra, Bosnia and Herzegovina, Faroe Islands, Gibraltar, Macedonia, Monaco, San Marino, Serbia and Montenegro
82	Kazakhstan	Kazakhstan
83	Kyrgyztan	Kyrgyzstan
84	Rest of Former Soviet Union	Tajikistan, Turkmenistan, Uzbekistan
85	Armenia	Armenia
86	Azerbaijan	Azerbaijan
87	Georgia	Georgia
88	Iran	Iran
89	Turkey	Turkey
90	Rest of Western Asia	Bahrain, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Palestinian Territory ,Qatar, Saudi Arabia, Syrian Arab Republic, United Arab Emirates, Yemen
91	Egypt	Egypt
92	Morocco	Morocco
93	Tunisia	Tunisia
94	Rest of North Africa	Algeria, Libyan Arab Jamahiriya
95	Nigeria	Nigeria
96	Senegal	Senegal
97	Rest of Western Africa	Benin, Burkina Faso, Cape Verde, Cote d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Mauritania, Niger, Saint Helena, Sierra Leone, Togo
98	Rest of Central Africa	Cameroon, Central African Republic, Chad, Congo, Equatorial Guinea, Gabon, Sao Tome and Principe
99	Rest of South Central Africa	Angola, Congo
100	Ethiopia	Ethiopia
101	Madagascar	Madagascar
102	Malawi	Malawi
103	Mauritius	Mauritius
104	Mozambique	Mozambique
105	Tanzania	Tanzania
106	Uganda	Uganda
107	Zambia	Zambia
108	Zimbabwe	Zimbabwe
109	Rest of Eastern Africa	Burundi, Comoros, Djibouti, Eritrea, Kenya, Mayotte, Reunion, Rwanda, Seychelles, Somalia
110	Botswana	Botswana
111	South Africa	South Africa
112	Rest of South African Customs	Lesotho, Namibia, Swaziland

Table A2 Sector and category for this study

No.	Sector	GTAP sector	Product category
1	Agriculture	Paddy rice; Wheat; Cereal grains nec; Vegetables, fruit, nuts; Oil seeds; Sugarcane, sugar beet; Plant-based fibers; Crops nec; Cattle, sheep, goats, horses; Animal products nec; Raw milk; Wool, silk-worm cocoons; Forestry; Fishing	Agricultural Product
2	Coal	Coal	Non-food Product (Mining, Extraction, and Utility)
3	Oil	Oil	Non-food Product (Mining, Extraction, and Utility)
4	Gas	Gas	Non-food Product (Mining, Extraction, and Utility)
5	Minerals nec	Minerals nec	Non-food Product (Mining, Extraction, and Utility)
6	Meat: cattle, sheep, goats, horses	Meat: cattle, sheep, goats, horses	Processed Food
7	Meat products nec	Meat products nec	Processed Food
8	Vegetable oils and fats	Vegetable oils and fats	Processed Food
9	Dairy products	Dairy products	Processed Food
10	Processed rice	Processed rice	Processed Food
11	Sugar	Sugar	Processed Food
12	Food products nec	Food products nec	Processed Food
13	Beverages and tobacco products	Beverages and tobacco products	Processed Food
14	Textiles	Textiles	Non-food Product (Other Light Manufacture)
15	Wearing apparel	Wearing apparel	Non-food Product (Other Light Manufacture)
16	Leather products	Leather products	Non-food Product (Other Light Manufacture)
17	Wood products	Wood products	Non-food Product (Other Light Manufacture)
18	Paper products, publishing	Paper products, publishing	Non-food Product (Other Light Manufacture)
19	Petroleum, coal products	Petroleum, coal products	Non-food Product (Other Heavy Manufacture)
20	Chemical, rubber, plastic products	Chemical, rubber, plastic products	Non-food Product (Other Heavy Manufacture)
21	Mineral products nec	Mineral products nec	Non-food Product (Other Heavy Manufacture)
22	Ferrous metals	Ferrous metals	Non-food Product (Other Heavy Manufacture)
23	Metals nec	Metals nec	Non-food Product (Other Heavy Manufacture)
24	Metal products	Metal products	Non-food Product (Other Light Manufacture)
25	Motor vehicles and parts	Motor vehicles and parts	Non-food Product (Other Light Manufacture)
26	Transport equipment nec	Transport equipment nec	Non-food Product (Other Light Manufacture)
27	Electronic equipment	Electronic equipment	Non-food Product (Other Heavy Manufacture)
28	Machinery and equipment nec	Machinery and equipment nec	Non-food Product (Other Heavy Manufacture)
29	Manufactures nec	Manufactures nec	Non-food Product (Other Light Manufacture)
30	Electricity	Electricity	Non-food Product (Mining, Extraction, and Utility)
31	Gas manufacture, distribution	Gas manufacture, distribution	Non-food Product (Mining, Extraction, and Utility)
32	Water collection, purification, and distribution	Water collection, purification, and distribution	Non-food Product (Mining, Extraction, and Utility)
33	Construction	Construction	Non-food Product (Construction)
34	Trade	Trade	Non-food Product (Trade, Transportation, and Communication)
35	Transport nec	Transport nec	Non-food Product (Trade, Transportation, and Communication)

(*Continued*)

No.	Sector	GTAP sector	Product category
36	Sea transport	Sea transport	Non-food Product (Trade, Transportation, and Communication)
37	Air transport	Air transport	Non-food Product (Trade, Transportation, and Communication)
38	Communication	Communication	Non-food Product (Trade, Transportation, and Communication)
39	Financial services nec	Financial services nec	Non-food Product (Other Services)
40	Insurance	Insurance	Non-food Product (Other Services)
41	Business services nec	Business services nec	Non-food Product (Other Services)
42	Recreation and other services	Recreation and other services	Non-food Product (Other Services)
43	Public Administration, Defense, Health, Education	Public Administration, Defense, Health, Education	Non-food Product (Other Services)
44	Dwellings	Dwellings	Non-food Product (Other Services)

Note: "nec" stands for "not elsewhere classified"