Globalization Drives Environmental Pressure in China

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ABSTRACT

In today's increasingly globalized economy, international trade chains accelerate China's environmental pressure due to consumption far from the place of production. We use a global multiregional input-output model to assess the environmental pressure for China. We comprehensively quantify China's total environmental pressures (resource consumption and pollutant emissions) caused by consumption all over the world using Environmental footprints (including water footprints, land footprints, material footprints, and emission footprints). Environmental footprints take the consumer responsibility approach to account for the environmental effects of consumption activities occurred in other countries. We assess (1) the quantity of China's environmental pressure are induced by the consumption activities of other countries in the world; (2) the displacement of China's resource consumption and pollutant emissions through exports of products with embodied pressures; (3) the key international supply chains or structural path causing China's environmental pressure (Structural Path Analysis is able to provide a collectively exhaustive and mutually exclusive representation of material flows in a global economic system). Our study emphasizes the importance of examining China's environmental pressure as a global systemic phenomenon, instead of looking at the resource consumption and/or pollutant emissions in isolation.

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1.Introduciton

Globalization is characterized by the international specialization of production activities and by the ever increasing volumes of international trade. It has integrated the different regions into global processes of industrilization and led to the separations of production and consumption activities, accompanying environmental pressure in one region being caused by consumption in another. In this interlinked process, China has become the world's top producer of global environmental pressures, such as material consumption(Wiedmann et al. 2013), iron ore(Wiedmann, Schandl and Moran 2014), land use(Yu, Feng and Hubacek 2013), greenhouse gases(Gregg, Andres and Marland 2008; Tukker et al. 2014), atmospheric mercury(Pacyna et al. 2010; Liang et al. 2014), and major producer of water usage(Lenzen et al. 2013) and bauxite(Wiedmann, Schandl and Moran 2014). The questions that arise are: how much China's environmental pressure is dislocated from its own territories? how China's environmental pressure is distributed in various destinations of consumption? is it important to mitigate China's environmental pressure along the global supply chains for achieving environmental sustainability in both China and the world?

To answering these questions, many studies have been limited mainly to energy usage(Li, Song and Liu 2014; Zeng et al. 2014; Zhang and Lahr 2014), CO_2 emission(Minx et al. 2011; Weber et al. 2008; Xu et al. 2011; Lin and Sun 2010; Guan et al. 2008; Peters et al. 2007), and atmospheric pollutant emissions(He 2010; Liang, Xu, et al. 2013; Zhang et al. 2013). However, such studies are neither sysmetic or comprehensive in their coverage of international trade and environmental satellite accounts. They also do not link exports to consuming countries, and China's environmental pressure more difficult to be tracked across global supply chains.

Our approach provides a comprehensive view of China's environmental pressure spreading around the world. Compiling inventries for 32 types of resources and emssions in China for the year 2010, we associated China's environmental pressure with embodied commodities; for example, the water usage in China's agricultural production linked to the consumption of the food, beverages and tobacco in America and Japan. Using a global multi-region input-output table, we trace the embodied commodities from China's production, through serveral intermediate trade and transformation steps, to the country of final consumption. this is the first time, to our knowledge, that the important role of globalization (international trade and foreign consumption) as a driver of China's environmental pressure has been comprehensively quantified.

2.Methods and Data

2.1 Environmental footprints of countries

We use the amount of water usage, land use, and material flows(Eurostat 2001) to represent environmental pressure. Considering 32 categories of China's environmental flows including 8 types of resources and 24 types of emissions and wastes, We

calculated China's environmental pressure caused by the world from the consumption-based perspective. The consumption-based perspective allocates China's environmental flows to countries whose final demand drives China's environmental flows through global supply chains (named 'footprints'). This perspective reflects life cycle environmental flows of final consumption activities in countries. The environmental footprints of countries based on the consumption accounting frameworks are calculated by the environmentally-extended multi-regional input-output (EE-MRIO) model(Wiedmann et al. 2007; Wiedmann 2009).

Assume the economy contains *m* regions, and each region contains *n* economic sectors and *p* final demand categories. We can calculate environmental footprints of countries of supply chains by equations (1).

$$\text{Consumption-based footprints of region } r = q\,(I-A)^{-1}\,y_c^{\square r} \qquad (1)$$

The matrix q represents the environmental intensity for one unit of total output of each sector in each region, termed as '*direct intensity*' of sectors. The matrix q only has elements for China, with elements for other regions as zeroes in this study.

The notation *I* represents the identity matrix. The matrix $(\mathrm{I}-\mathrm{A})^{-1}$ is usually named as *Leontief inverse* matrix(Miller and Blair 2009), whose element l_{ij} indicates both direct and indirect requirements of products from sector *i* to produce one unit of final demand for sector *j*. The block matrix A is the direct requirement coefficient matrix (also named as technical coefficient matrix), whose element a_{ij} indicates the direct requirement of products from sector *i* to produce one unit of total output in sector *j*. The matrix $q(I-A)^{-1}$ is termed as '*life cycle intensity*' of sectors in this study, meaning both direct and indirect emissions caused by one unit final demand of a particular sector. The column vector $y_c^{\square r}$ represents product flows from all regions to the final demand of region *r*. The subscript *c* means final demand of a region. The formats of A and $f_c^{\square r}$ are shown in equations (2) and (3).

$$\mathrm{A}=\begin{pmatrix} \mathrm{A}^{11} & \cdots & \mathrm{A}^{1s} & \cdots & \mathrm{A}^{1n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \mathrm{A}^{r1} & \cdots & \mathrm{A}^{rs} & \cdots & \mathrm{A}^{rn} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \mathrm{A}^{n1} & \cdots & \mathrm{A}^{ns} & \cdots & \mathrm{A}^{nn} \end{pmatrix} \qquad (2)$$

$$y_c^{\square r}=\begin{pmatrix} \sum_{j=1}^{q} y_{ij}^{1r} \\ \cdots \\ \sum_{j=1}^{q} y_{ij}^{sr} \\ \cdots \\ \sum_{j=1}^{q} y_{ij}^{nr} \end{pmatrix} \qquad (3)$$

The element y_{ij}^{sr} indicates the j^{th} category of final demand in region *r* on products of sector *i* in region *s*. By diagonalizing the column vectors $y_c^{\square r}$ in equations (1), we can disaggregate results to the sector scale.

2.2 Structural path analysis

Global supply chains are extracted by the structural path analysis (SPA), which is based on the Taylor expansion of the *Leontief inverse* matrix of the EE-MRIO model(Lenzen, Schaeffer and Matsuhashi 2007).

$$(I-A)^{-1} = I + A + A^2 + A^3 + \ldots + A^n, \ \lim_{n\to\infty}(A^n) = 0 \quad (4)$$

The SPA based on the EE-MRIO model can extract important supply chains causing environmental flows by equation (5)

$$\text{footprints} = q\,(I + A + A^2 + A^3 + \ldots + A^n)\,\text{diag}(y_i)$$

$$= q\,I\,\text{diag}(y_i) + q\,A\,\text{diag}(y_i) + q\,A^2\text{diag}(y_i) + \ldots + q\,A^n\text{diag}(y_i) \quad (5)$$

where the column vector y_i indicates the final demand for products from sector *i*. The notation "diag" means diagonalizing the vector within the parenthesis. Each term in the right-hand side of equation (5) is defined as a production layer (PL).

2.3 Data sources

The world MRIO table for the year 2010 is from the World Input-Output Database (WIOD, released in November 2013), covering 27 European Union countries and 13 other major countries (Table A1)(Dietzenbacher et al. 2013). Each country is further divided into 35 economic sectors (Table A2)(Dietzenbacher et al. 2013).

This study considers 8 categories of resource flows and 24 categories of emissions and waste flows (Table A3). Most of the data are from Liang et al.(2013)(Liang, Liu, et al. 2013) . Land use including cultivated land, garden land, grazing and pasture land, forest area, transport land, water conservancy land, and rural and mining land, is from *The Second National Land Survey of China*(Ministry of Land and Resources of China and National Bureau of Statistics of China 2013) and *China Land and Resources Statistical Yearbook*(Ministry of Land and Resources of China 2011). We allocated the data of land use to the world MRIO sectors of agriculture, hunting, forestry and fishing, transport, electricity, gas and water supply, and other services. Each sector's energy usage is from *China Energy Statistical Yearbooks*(National Bureau of Statistics of China 2011). Energy usage by agricultural sectors is aggregated. We disaggregate this data for each agricultural sector using the intermediate allocation data of energy sources in China's input-output table(National Bureau of Statistics of China 2013).

The sector classification of the world MRIO table is different from that of the Liang et al.'s work, which is from China's national input-output table(National Bureau of Statistics of China 2013). We reconcile the sector classification of China's national

input-output table to make it consistent with that of the WIOD. This reconciliation is performed by constructing a prorating matrix using a binary concordance matrix which is based on the ratios of proxy vectors(Lenzen et al. 2012). The values in a concordance matrix are either 0 or 1, determining how the target value is split between the original sector classification and the target sector classification.

Let the matrix C represent an $m \times n$ binary concordance matrix, the $n \times 1$ vector x represent sectoral total output, and the $n \times n$ matrix $\hat{x}$ represent the diagonal matrix of the vector x. The $m \times n$ normalized map M based on the matrix C is shown in equation (7). Data for sectoral total output x are from the WIOD.

$$M = (Cx)^{-1} C\hat{x} \tag{7}$$

3.Results

To facilitate reportting and discussuin of our results, we group 32 types of China's environmental flows into four grand categories, containing water, land use, material use (energy, biomass, and mineral ores), and emissions (air pollutants, water pollutants, and solid wastes).

3.1 Environmental footprints of countries

For the year 2010, the consumption of other countries are responsible for 6.57 of water usage (37.3 Gt), 7.02% of land use (55.2 Mha), 13.16% of material use (1.48Gt), and 12.42% of emissions (1.65 Gt) in China, respectively. Among the top consumers, the developed and emerging countries, such as USA, Japan, Germany, South Korea, Australia, Canada, United Kingdom, are the main final destinations of China's environmental-embodied products (Figure 1, Left), accounting for 45% of total export footprints for each environmental category. For comparison, 10% of China's total export footprints of each environmental category were induced by developing India, Indonesia, and Mexico.

Countries function differently in gross footprints and per-capita footprints during China's production of goods and services that were ultimately consumed in the world. The USA economy had by far the largest consumer of China's environmental pressure in gross values of footprints (7.4 Gt of water footprint, 10.6 Mha of land use footprint, 28.8 Mt of material use footprint, and 31.9 Mt of emission footprint), twofold and a half as large as those of the Japan, and fourfold those of Gernmany and India. Sixty percent of American material footprint (18.42 Mt) consists of ferrous metal ores, nonferrous metal ores, and nonmetallic ores. Ninety percent of American emission footpints (29.79 Mt) are from CO_2 emission.

Although Ireland has the highest per-capita water footprint (53.97 t/cap) and land footprint (736.41m^2/cap), and Austrilia is top consumer in per-capita material footprint (1.74 t/ cap) and emission footprint (2.08 t/ cap), other developed economies show similar levels above 25 t/cap of water footprint, 400m^2/cap of land footprint, 1 t/ cap of material footprint and emission footprint (e.g.the Netherlands, South Korea,

Belgium, Canada, Finland) (Figure 1, Right). A lower environmental standard of living and a lower average level of consumption in developing countries are reflected in the footprints below 3 t/cap of water footprint, 50m^2/cap of land footprint, 0.15 t/ cap of material footprint and emission footprint. Particularly, India at the lower end of the four environmental footprints (1.46 t/cap of water footprint, 22.61 m^2/cap of land footprint, and 0.06 t/ cap of material footprint and emission footprint).

3.2 Environmental footprint of sectors

Sectoral structure of the global economy determines its functionality. Disaggregated environmental footprints to basic units of the global production system – sectors, we found that manufacturing (e.g. food, beverages and tobacco, textiles and textile products, machinery, electrical and optical equipment, transport equipment, and other manufacturing), construction, and services (e.g. public administration and social security, health and social work, and other services) are the major environmental-embodied sectors that ultimately consumed in developed countries or emerging economies (e.g. Austrilia, Canada, Italy, Germany, United Kingdom, Japan, South Korea, and the United States and developing countries (e.g. Brazil, Indonesia, India, Mexico, and Turkey) (Figure 2 and Table A4).

These major destined sectors are water-intensive, material-intensive, emission-intensive, and less land-intensive, accouting for 35.59% (14.77Gt water), 44.41 %(657.29 Mt material use),45.87% (758.90 Mt emissions), and 23.88% (13.23Mha land use) of their total export footprints, respectively. In particular, the United Stated as the largest contribtor, most of its sectors are environment-intensive, contributing 6.73Gt (18.03% of total water exports), 7.48Mha(13.57% of total water exports), 268.17Mt (18.12% of total material exports), and 300.18Mt (18.15% of total emission exports) to the China's environmental pressure exports, respectively.

Global supply chains extracted by the structural path analysis connect China's production usage and emissions with the final demand contributors. Major international supply chains causing China's water and land pressure (Table 1 and Table 2) are mainly related with the sector of agriculture, hunting, forestry and fishing, agricultural products supply to the manufacturing actvities of food, beverages and tobacco, textiles and textile products, leather, leather and footwear, and public administration and social security in developed countries (e.g. the United Sates, Japan, South Korea, Italy, and The Netherlands) and developing countries (e.g. India, Turkey, and Mexico). The largest supply chain is "Agriculture, Hunting, Forestry and Fishing in China→Food, Beverages and Tobacco in the United States" in both water and land footprint, producing 144.24 Mt (0.025% of total water exports) and 275.74Kha (0.035% of totoal land exports) during China's production, respectively (Table 1 and Table 2). On the other hand, international supply chains contributing to the materila use and CO_2 emission pressure are mainly related with other non-metallic mineral, basic metals and fabricated metal, chemicals and chemical products in China. these sectors provided raw materials to construction activities, the manufacture of electrical and optical equipment, public admin and social security in the United States, Japan, South Korea, India, Turkey, and Mexico (Table 3 and Table 4).

4.Discussion

This study comprehensively quantified the important role of international trade and foreign consumption as a driver of China's environmental pressure. International trades cause the leakages of embodied resource usage and emissions across global supply chains. Considering environmental footprints of countries within global supply chains during the allocation of environmental reduction responsibilities can avoid such kind of leakage.

Traditional environmental flow accounting is from the production perspective which is limited to direct sources within China's geographic boundaries. This study considers effects of global supply chains on China's environmental footprints (water, land, material use, and emissions), informing the allocation of China's environmental reduction responsibility to consider environmental footprints of countries along global supply chains, that is, sharing all of production-based and consumption-based environmental responsibilities.

Global consumption is an underlying drivers of China production. The globally final demands are not only from developed countries (e.g. the United States, Japan, and Germany) or emerging economies (e.g. South Korea), but also from developing countries (e.g. India, Indonsia, and Mexico). It is necessary to take actions at different countries to reduce China's environmental pressure with least policy cost than only at developed countries. If responsibility allocation only considers developed countries or emerging economies, Part of the leakages of embodied resource usage and emissions caused by India, Indonsia, and Mexicao will be ignored in the global supply chains. For example, if India seeks to use more environment-intensive raw materials from China which may be cheaper, resource consumption and environmental emissions of the upstream China will still be increased and efforts of corresponding upstream China and other consumers will be offset. Such situation will increase the global policy cost in China environmental reductions.

Considering global supply chain effects on China also enables this study to identify 'hot spots' for China environmental abatement from consumers at the sector scale – basic units of the global production system. Key sectors contributing to China's production-based resource uses and emissions should be the focus of traditional production-side actions (e.g. improving the production technolgy, implementing cleaner production and installing emission removal facilities in sectors producing agriculture, hunting, forestry and fishing, non-metallic mineral products, metals, mineral ores, and chemicals). On the other hand, key sectors contributing to consumption-based resource uses and emissions should be the focus of demand-side actions (e.g. limiting the surplus production of foods, machinery, equipment, construction, and services, and optimizing their material input recipes during the production and consumption). Actions reducing China's environmental pressure at the sector scale (e.g. life cycle product design) should cover those key sectors from both prodution and consumption sides. Major supply chains illustrate primary interconnection paths between prodution and consumption key sectors. They uncover

the important transfer paths of embodied environmental flows as well as the transfer paths of effects of possible actions, directing the emphases for life cycle product design and sustainable global supply chain management.

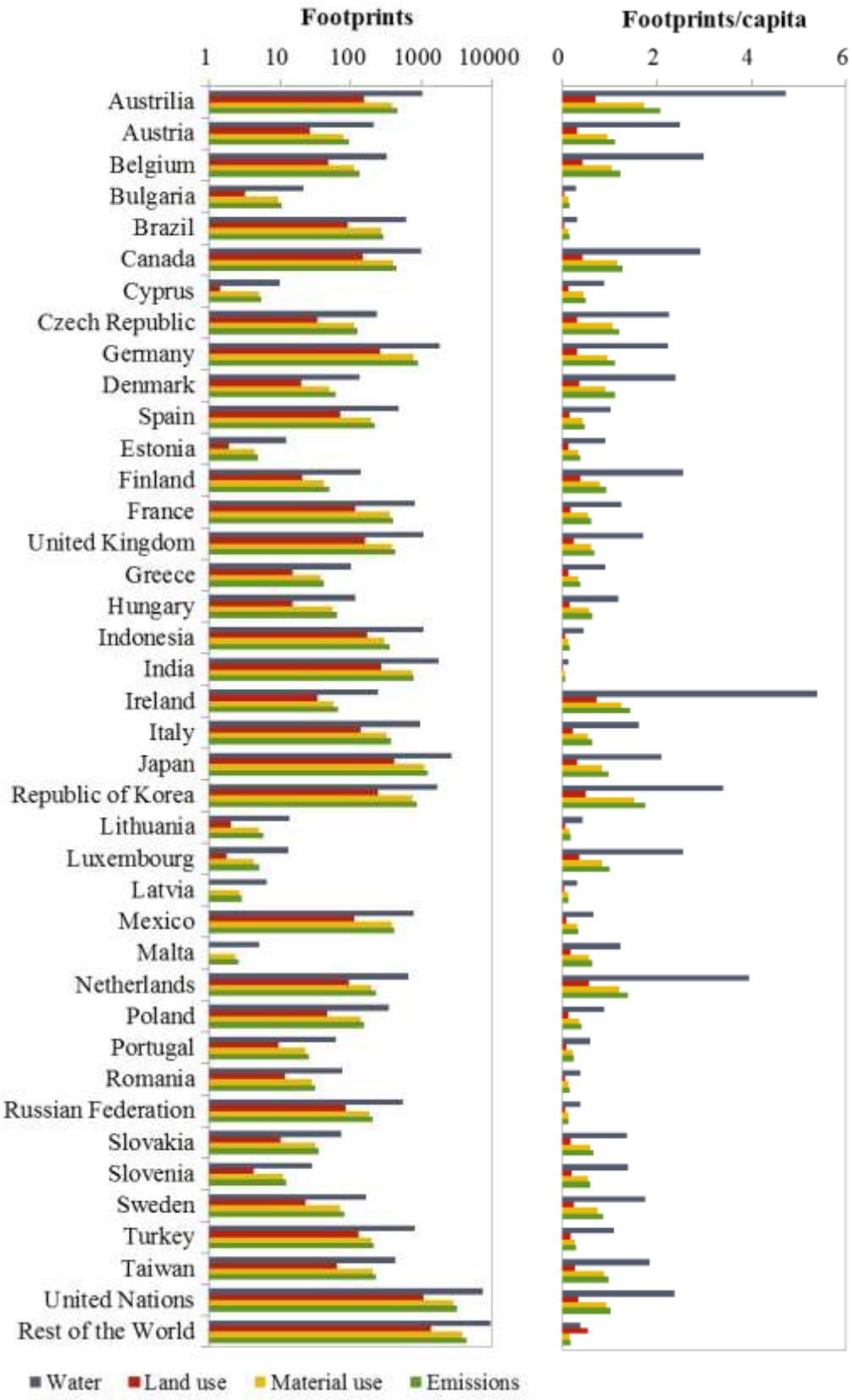

Figure 1. Water footprint (Mt), land footprint (10^4 ha), material footprint (10^4 t), and emissions and waste footprint (10^4 t) of embodied in China's exports to other countries in 2010, expressed in totals and per capita (left to right).

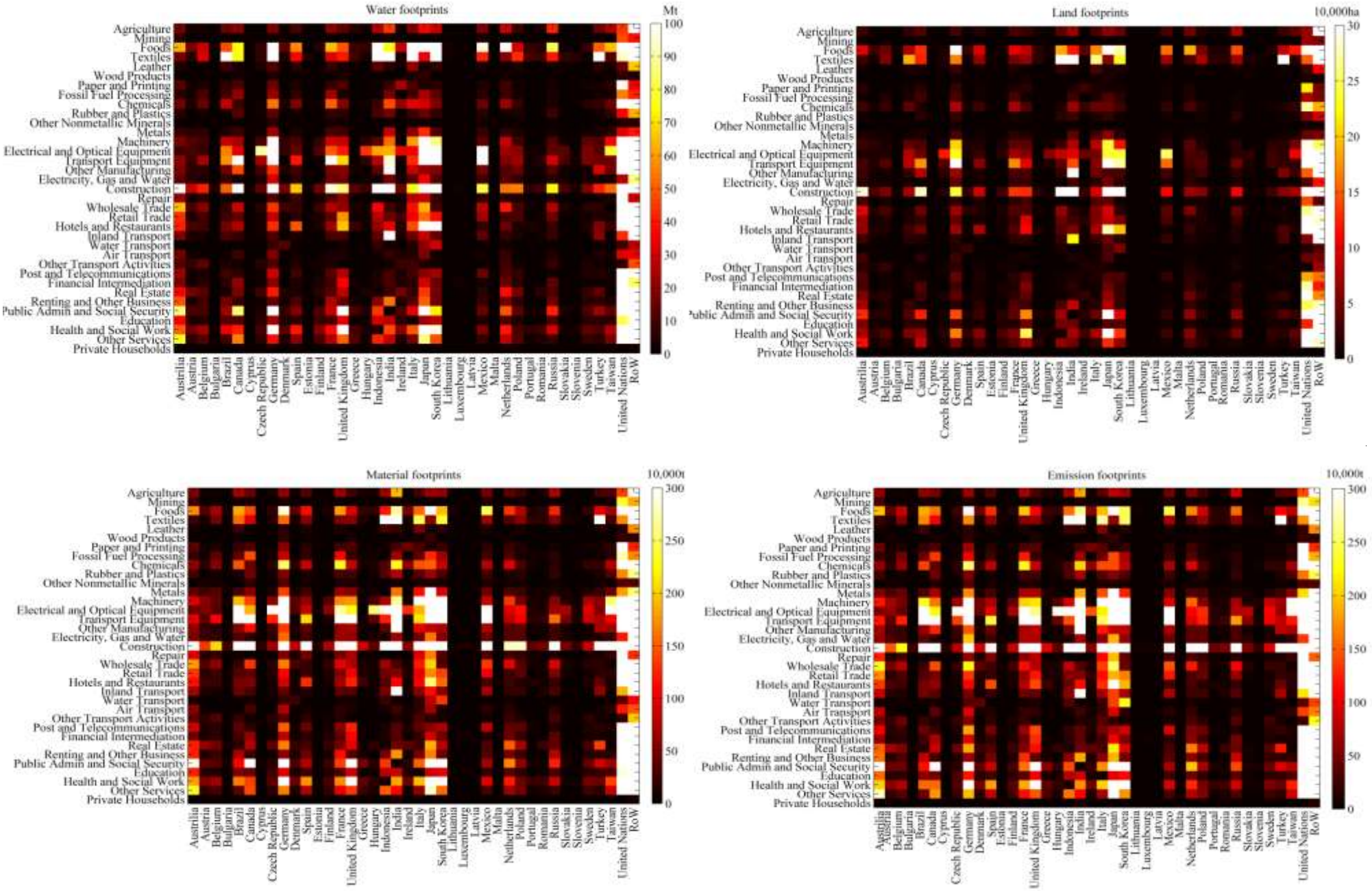

Figure 2. Sectoral quantity of water, land, material flow, and emissions. The environmental footprint quantities of top 30 sectors are shown in Table A4.

Table 1. Top 20 international supply chains causing China's water usage.

Rank	Supply chain paths	Water usage (Mt)	Contribution to total water exports
1	CHN-Agriculture, Hunting, Forestry and Fishing → USA-Food, Beverages and Tobacco	144.24	0.025%
2	CHN-Agriculture, Hunting, Forestry and Fishing → JPN-Food, Beverages and Tobacco	138.43	0.024%
3	CHN-Agriculture, Hunting, Forestry and Fishing → CHN-Textiles and Textile Products → TUR-Textiles and Textile Products	84.44	0.015%
4	CHN-Agriculture, Hunting, Forestry and Fishing → CHN-Textiles and Textile Products → IDN-Textiles and Textile Products	80.98	0.014%
5	CHN-Agriculture, Hunting, Forestry and Fishing → CHN-Leather, Leather and Footwear → USA- Public Admin and Social Security	75.57	0.013%
6	CHN-Agriculture, Hunting, Forestry and Fishing → DEU-Food, Beverages and Tobacco	74.03	0.013%
7	CHN-Agriculture, Hunting, Forestry and Fishing → CHN-Manufacturing, Nec; Recycling → IND-Manufacturing, Nec; Recycling	61.83	0.011%
8	CHN-Agriculture, Hunting, Forestry and Fishing → KOR-Food, Beverages and Tobacco	58.81	0.010%
9	CHN-Renting of M&Eq and Other Business Activities → USA- Public Admin and Social Security	56.55	0.010%
10	CHN-Agriculture, Hunting, Forestry and Fishing → USA-Hotels and Restaurants	47.59	0.008%
11	CHN-Agriculture, Hunting, Forestry and Fishing → NLD-Food, Beverages and Tobacco	46.45	0.008%
12	CHN-Agriculture, Hunting, Forestry and Fishing → CHN-Textiles and Textile Products → USA- Public Admin and Social Security	44.34	0.008%
13	CHN-Agriculture, Hunting, Forestry and Fishing → IDN-Food, Beverages and Tobacco	38.66	0.007%
14	CHN-Agriculture, Hunting, Forestry and Fishing → ITA-Food, Beverages and Tobacco	37.80	0.007%
15	CHN-Agriculture, Hunting, Forestry and Fishing → CHN-Textiles and Textile Products → CHN-Textiles and Textile Products → TUR-Textiles and Textile Products	36.93	0.007%
16	CHN-Agriculture, Hunting, Forestry and Fishing → CHN-Textiles and Textile Products → CHN-Textiles and Textile Products → IDN-Textiles and Textile Products	35.42	0.006%
17	CHN-Agriculture, Hunting, Forestry and Fishing → CHN-Food, Beverages and Tobacco → CHN-Leather, Leather and Footwear → USA- Public Admin and Social Security	33.43	0.006%
18	CHN-Agriculture, Hunting, Forestry and Fishing → CHN-Textiles and Textile Products → ITA-Textiles and Textile Products	32.14	0.006%
19	CHN-Agriculture, Hunting, Forestry and Fishing → CHN-Textiles and Textile Products → TUR-Textiles and Textile Products → TUR-Textiles and Textile Products	30.69	0.005%
20	CHN-Agriculture, Hunting, Forestry and Fishing → TWN-Food, Beverages and Tobacco'	29.28	0.005%

Table 2. Top 20 international supply chains causing China's land use.

Rank	Supply chain paths	Land use (Kha)	Contribution to total land exports
1	CHN-Agriculture, Hunting, Forestry and Fishing → USA-Food, Beverages and Tobacco	275.74	0.035%
2	CHN-Agriculture, Hunting, Forestry and Fishing → JPN-Food, Beverages and Tobacco	264.63	0.034%
3	CHN-Agriculture, Hunting, Forestry and Fishing → CHN-Textiles and Textile Products → TUR-Textiles and Textile Products	161.43	0.021%
4	CHN-Agriculture, Hunting, Forestry and Fishing → CHN-Textiles and Textile Products → IDN-Textiles and Textile Products	154.81	0.020%
5	CHN-Agriculture, Hunting, Forestry and Fishing → CHN-Leather, Leather and Footwear → USA- Public Admin and Social Security	144.47	0.018%
6	CHN-Agriculture, Hunting, Forestry and Fishing → DEU-Food, Beverages and Tobacco	141.52	0.018%
7	CHN-Agriculture, Hunting, Forestry and Fishing → CHN-Manufacturing, Nec; Recycling → IND-Manufacturing, Nec; Recycling	118.20	0.015%
8	CHN-Agriculture, Hunting, Forestry and Fishing → KOR-Food, Beverages and Tobacco	112.42	0.014%
9	CHN-Agriculture, Hunting, Forestry and Fishing → USA-Hotels and Restaurants	90.98	0.012%
10	CHN-Agriculture, Hunting, Forestry and Fishing → NLD-Food, Beverages and Tobacco	88.81	0.011%
11	CHN-Agriculture, Hunting, Forestry and Fishing → CHN-Textiles and Textile Products → USA- Public Admin and Social Security	84.76	0.011%
12	CHN-Agriculture, Hunting, Forestry and Fishing → IDN-Food, Beverages and Tobacco	73.91	0.009%
13	CHN-Agriculture, Hunting, Forestry and Fishing → ITA-Food, Beverages and Tobacco	72.27	0.009%
14	CHN-Agriculture, Hunting, Forestry and Fishing → CHN-Textiles and Textile Products → CHN-Textiles and Textile Products → TUR-Textiles and Textile Products	70.60	0.009%
15	CHN-Agriculture, Hunting, Forestry and Fishing → CHN-Textiles and Textile Products → CHN-Textiles and Textile Products → IDN-Textiles and Textile Products	67.71	0.009%
16	CHN-Agriculture, Hunting, Forestry and Fishing → CHN-Food, Beverages and Tobacco → CHN-Leather, Leather and Footwear → USA- Public Admin and Social Security	63.91	0.008%
17	CHN-Agriculture, Hunting, Forestry and Fishing → CHN-Textiles and Textile Products → ITA-Textiles and Textile Products	61.45	0.008%
18	CHN-Agriculture, Hunting, Forestry and Fishing → CHN-Textiles and Textile Products → TUR-Textiles and Textile Products → TUR-Textiles and Textile Products	58.67	0.007%
19	CHN-Agriculture, Hunting, Forestry and Fishing → TWN-Food, Beverages and Tobacco	55.98	0.007%
20	CHN-Agriculture, Hunting, Forestry and Fishing → MEX-Food, Beverages and Tobacco	52.77	0.007%

Table 3. Top 20 international supply chains causing China's material use.

Rank	Supply chain paths	Material flow (Mt)	Contribution to total material exports
1	CHN-Other Non-Metallic Mineral → USA-Construction	4.76	0.042%
2	CHN-Other Non-Metallic Mineral → IND-Construction	3.46	0.031%
3	CHN-Other Non-Metallic Mineral → JPN-Construction	2.88	0.026%
4	CHN-Other Non-Metallic Mineral → KOR-Construction	2.53	0.022%
5	CHN-Basic Metals and Fabricated Metal → JPN-Construction	2.40	0.021%
6	CHN-Manufacturing, Nec; Recycling → IND-Manufacturing, Nec; Recycling	1.98	0.018%
7	CHN-Basic Metals and Fabricated Metal → USA-Construction	1.86	0.017%
8	CHN-Chemicals and Chemical Products → JPN-Health and Social Work	1.85	0.016%
9	CHN-Chemicals and Chemical Products → USA-Chemicals and Chemical Products	1.68	0.015%
10	CHN-Basic Metals and Fabricated Metal → IDN-Construction	1.52	0.014%
11	CHN-Basic Metals and Fabricated Metal → KOR-Construction	1.49	0.013%
12	CHN-Basic Metals and Fabricated Metal → CHN-Electrical and Optical Equipment → USA- Public Admin and Social Security	1.47	0.013%
13	CHN-Basic Metals and Fabricated Metal → USA-Transport Equipment	1.41	0.013%
14	CHN-Other Non-Metallic Mineral → TUR-Construction	1.25	0.011%
15	CHN-Other Non-Metallic Mineral → CAN-Construction	1.24	0.011%
16	CHN-Other Non-Metallic Mineral → DEU-Construction	1.23	0.011%
17	CHN-Chemicals and Chemical Products → USA-Health and Social Work	1.21	0.011%
18	CHN-Basic Metals and Fabricated Metal → CHN-Electrical and Optical Equipment → USA-Electrical and Optical Equipment	1.05	0.009%
19	CHN-Chemicals and Chemical Products → USA- Public Admin and Social Security	0.98	0.009%
20	CHN-Basic Metals and Fabricated Metal → CHN-Electrical and Optical Equipment → MEX-Electrical and Optical Equipment	0.97	0.009%

Table 4. Top 20 international supply chains causing China's CO_2 emissions.

Rank	Supply chain paths	CO_2 (Mt)	Contribution to total emission exports
1	CHN-Basic Metals and Fabricated Metal → JPN-Construction	3.44	0.033%
2	CHN-Other Non-Metallic Mineral → USA-Construction	3.35	0.032%
3	CHN-Basic Metals and Fabricated Metal → USA-Construction	2.67	0.026%
4	CHN-Other Non-Metallic Mineral → IND-Construction	2.43	0.023%
5	CHN-Basic Metals and Fabricated Metal → IDN-Construction	2.18	0.021%
6	CHN-Basic Metals and Fabricated Metal → KOR-Construction	2.13	0.020%
7	CHN-Basic Metals and Fabricated Metal → CHN-Electrical and Optical Equipment → USA- Public Admin and Social Security	2.10	0.020%
8	CHN-Other Non-Metallic Mineral → JPN-Construction	2.03	0.019%
9	CHN-Basic Metals and Fabricated Metal → USA-Transport Equipment	2.02	0.019%
10	CHN-Other Non-Metallic Mineral → KOR-Construction	1.78	0.017%
11	CHN-Basic Metals and Fabricated Metal → CHN-Electrical and Optical Equipment → USA-Electrical and Optical Equipment	1.50	0.014%
12	CHN-Basic Metals and Fabricated Metal → CHN-Electrical and Optical Equipment → MEX-Electrical and Optical Equipment	1.39	0.013%
13	CHN-Basic Metals and Fabricated Metal → USA-Machinery, Nec	1.39	0.013%
14	CHN-Basic Metals and Fabricated Metal → CAN-Construction	1.17	0.011%
15	CHN-Basic Metals and Fabricated Metal → CHN-Basic Metals and Fabricated Metal → JPN-Construction	1.15	0.011%
16	CHN-Basic Metals and Fabricated Metal → IND-Construction'	1.05	0.010%
17	CHN-Basic Metals and Fabricated Metal → CHN-Electrical and Optical Equipment → DEU-Electrical and Optical Equipment'	1.03	0.010%
18	CHN-Basic Metals and Fabricated Metal → CHN-Electrical and Optical Equipment → USA-Transport Equipment'	1.02	0.010%
19	CHN-Basic Metals and Fabricated Metal → KOR-Basic Metals and Fabricated Metal → KOR-Construction'	0.96	0.009%
20	CHN-Basic Metals and Fabricated Metal → AUS-Construction'	0.91	0.009%

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Appendix

Table A1. The list of countries in the world MRIO table.

No.	Names	Abbreviations	No.	Names	Abbreviations
1	Australia	AUS	22	Italy	ITA
2	Austria	AUT	23	Japan	JPN
3	Belgium	BEL	24	South Korea	KOR
4	Bulgaria	BGR	25	Lithuania	LTU
5	Brazil	BRA	26	Luxembourg	LUX
6	Canada	CAN	27	Latvia	LVA
7	China	CHN	28	Mexico	MEX
8	Cyprus	CYP	29	Malta	MLT
9	Czech Republic	CZE	30	Netherlands	NLD
10	Germany	DEU	31	Poland	POL
11	Denmark	DNK	32	Portugal	PRT
12	Spain	ESP	33	Romania	ROM
13	Estonia	EST	34	Russia	RUS
14	Finland	FIN	35	Slovak Republic	SVK
15	France	FRA	36	Slovenia	SVN
16	United Kingdom	GBR	37	Sweden	SWE
17	Greece	GRC	38	Turkey	TUR
18	Hungary	HUN	39	Taiwan	TWN
19	Indonesia	IDN	40	United States	USA
20	India	IND	41	Rest of the World	RoW
21	Ireland	IRL			

Table A2. The list of sectors in the world MRIO table.

No.	Sector names	Abbreviations
1	Agriculture, Hunting, Forestry and Fishing	Agriculture
2	Mining and Quarrying	Mining
3	Food, Beverages and Tobacco	Foods
4	Textiles and Textile Products	Textiles
5	Leather, Leather and Footwear	Leather
6	Wood and Products of Wood and Cork	Wood Products
7	Pulp, Paper, Paper , Printing and Publishing	Paper and Printing
8	Coke, Refined Petroleum and Nuclear Fuel	Fossil Fuel Processing
9	Chemicals and Chemical Products	Chemicals
10	Rubber and Plastics	Rubber and Plastics
11	Other Non-Metallic Mineral	Other Nonmetallic Minerals
12	Basic Metals and Fabricated Metal	Metals
13	Machinery, Nec	Machinery
14	Electrical and Optical Equipment	Electrical and Optical Equipment
15	Transport Equipment	Transport Equipment
16	Manufacturing, Nec; Recycling	Other Manufacturing
17	Electricity, Gas and Water Supply	Electricity, Gas and Water
18	Construction	Construction
19	Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel	Repair
20	Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles	Wholesale Trade
21	Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods	Retail Trade
22	Hotels and Restaurants	Hotels and Restaurants
23	Inland Transport	Inland Transport
24	Water Transport	Water Transport
25	Air Transport	Air Transport
26	Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies	Other Transport Activities
27	Post and Telecommunications	Post and Telecommunications
28	Financial Intermediation	Financial Intermediation
29	Real Estate Activities	Real Estate
30	Renting of M&Eq and Other Business Activities	Renting and Other Business
31	Public Admin and Defence; Compulsory Social Security	Public Admin and Social Security
32	Education	Education
33	Health and Social Work	Health and Social Work
34	Other Community, Social and Personal Services	Other Services
35	Private Households with Employed Persons	Private Households

Table A3. Resources and pollutants considered in this study

Items	NO.	Environmental flows	Contents
Resource usages	1	Water	Freshwater
	2	Land	Land use
	3	Energy	Raw coal, washed coal, other washed coal, briquettes, crude oil, natural gas, coke, other coking products, gasoline, kerosene, diesel oil, fuel oil, other petroleum products, electric and heat power, coke oven gas, other gas, liquefied petroleum gas, refinery gas; hydropower, nuclear power, wind power and other renewable energy
	4	Agricultural products	Cereals, roots and tubers, pulses, oil crops, vegetables, fruits, tree nuts, fiber crops, other crops
	5	Forestry products	Log, forestry fruits
	6	Ferrous metal ores	Iron ore, manganese ore, chrome ore
	7	Nonferrous metal ores	Bauxite, copper ore, lead ore, zinc ore, tin ore, antimony ore, molybdenum ore, nickel ore, mercury ore, other non-ferrous ores
	8	Nonmetallic ores	Salts, special clays, special sands, sand and gravel, crushed stones, common clays, dimension stones, other non-metallic ores
Air pollutant emissions	9	Carbon dioxide (CO_2)	
	10	Methane (CH_4)	
	11	Nitrous oxide (N_2O)	
	12	Sulfur dioxide (SO_2)	
	13	Nitrogen oxides (NOx)	
	14	Soot	
	15	Dust	
	16	Mercury (Hg)	
	17	Arsenic (As)	
	18	Selenium (Se)	
Water pollutant emissions	19	Chemical oxygen demand (COD)	
	20	Ammonia nitrogen	
	21	Phosphorus (P)	
	22	Petroleum pollutants	
	23	Volatile phenol	
	24	Cyanide	
	25	Mercury (Hg)	

	26	Cadmium (Cd)
	27	Chromium (Cr)
	28	Lead (Pb)
	29	Arsenic (As)
	30	Copper (Cu)
	31	Zinc (Zn)
Solid wastes emissions	32	Hazardous wastes, smetery slag, coal ash, cinder, coal gangue, tailings, radioactive waste, desulfurized gypsum, agricultural plastic film, crop straws, animal manure, sludge, construction wastes, medical wastes

Table A4. Major sectors contributing to China's environmental pressure.

Rank	Water footprints			Land footprints		
	Country	Sector	Quantity (Mt)	Country	Sector	Quantity (Kha)
1	USA	Transport Equipment	616.13	USA	Public Admin and Social Security	2,405.19
2	USA	Construction	578.33	USA	Transport Equipment	869.82
3	USA	Health and Social Work	572.72	USA	Food, Beverages and Tobacco	866.24
4	USA	Food, Beverages and Tobacco	526.27	USA	Construction	810.47
5	TUR	Textiles and Textile Products	468.17	USA	Health and Social Work	809.24
6	JPN	Food, Beverages and Tobacco	415.72	TUR	Textiles and Textile Products	783.55
7	IND	Manufacturing, Nec; Recycling	394.54	JPN	Food, Beverages and Tobacco	729.72
8	JPN	Construction	390.26	IND	Manufacturing, Nec; Recycling	626.03
9	USA	Retail Trade	371.54	JPN	Construction	568.28
10	USA	Hotels and Restaurants	341.24	IDN	Textiles and Textile Products	549.86
11	IDN	Textiles and Textile Products	329.18	USA	Hotels and Restaurants	528.65
12	IND	Construction	291.37	USA	Retail Trade	522.37
13	KOR	Construction	270.29	IND	Construction	435.99
14	DEU	Transport Equipment	268.44	DEU	Transport Equipment	377.25
15	USA	Electrical and Optical Equipment	254.21	KOR	Construction	365.74
16	JPN	Health and Social Work	250.22	JPN	Health and Social Work	361.34
17	USA	Real Estate Activities	237.47	USA	Electrical and Optical Equipment	343.14
18	USA	Machinery, Nec	214.53	USA	Real Estate Activities	329.49
19	USA	Other Services	213.23	IND	Textiles and Textile Products	321.42
20	AUS	Construction	212.43	DEU	Food, Beverages and Tobacco	313.90
21	JPN	Transport Equipment	211.06	IDN	Construction	310.17
22	IDN	Construction	208.34	JPN	Public Admin and Social Security	299.79
23	USA	Financial Intermediation	208.06	USA	Other Services	298.95
24	IND	Textiles and Textile Products	200.61	JPN	Transport Equipment	296.15
25	JPN	Public Admin and Social Security	199.05	USA	Machinery, Nec	293.13
26	KOR	Transport Equipment	198.32	AUS	Construction	287.05
27	USA	Chemicals and Chemical Products	194.84	CAN	Construction	279.62
28	USA	Wholesale Trade	192.91	KOR	Food, Beverages and Tobacco	272.34
29	MEX	Electrical and Optical Equipment	188.89	USA	Financial Intermediation	272.32
30	CAN	Construction	187.93	JPN	Hotels and Restaurants	272.15

Table A4. Major sectors contributing to China's environmental pressure (Continued).

Rank	Material footprints			Emission footprints		
	Country	Sector	Quantity (Mt)	Country	Sector	Quantity (Mt)
1	USA	Public Admin and Social Security	54.99	USA	Public Admin and Social Security	112.01
2	USA	Construction	33.46	USA	Construction	68.26
3	USA	Transport Equipment	31.10	USA	Transport Equipment	61.53
4	JPN	Construction	22.69	JPN	Construction	44.94
5	USA	Health and Social Work	20.57	KOR	Construction	36.18
6	KOR	Construction	19.55	USA	Health and Social Work	35.75
7	IND	Construction	18.38	IND	Construction	24.20
8	IND	Manufacturing, Nec; Recycling	15.09	DEU	Transport Equipment	21.91
9	USA	Electrical and Optical Equipment	14.02	USA	Electrical and Optical Equipment	21.47
10	DEU	Transport Equipment	13.83	IND	Manufacturing, Nec; Recycling	21.15
11	USA	Retail Trade	13.51	USA	Retail Trade	19.68
12	USA	Machinery, Nec	12.60	USA	Machinery, Nec	18.80
13	USA	Food, Beverages and Tobacco	12.42	KOR	Transport Equipment	16.08
14	KOR	Transport Equipment	11.92	USA	Food, Beverages and Tobacco	15.03
15	JPN	Transport Equipment	11.74	JPN	Transport Equipment	14.39
16	MEX	Electrical and Optical Equipment	10.93	IDN	Construction	14.16
17	JPN	Health and Social Work	10.88	MEX	Electrical and Optical Equipment	14.08
18	AUS	Construction	10.72	JPN	Machinery, Nec	14.04
19	IDN	Construction	10.71	AUS	Construction	13.85
20	KOR	Electrical and Optical Equipment	10.39	KOR	Electrical and Optical Equipment	13.44
21	JPN	Machinery, Nec	10.32	DEU	Electrical and Optical Equipment	13.34
22	DEU	Construction	10.06	JPN	Electrical and Optical Equipment	12.37
23	CAN	Construction	9.98	CAN	Construction	12.30
24	JPN	Electrical and Optical Equipment	9.62	DEU	Construction	12.17
25	DEU	Electrical and Optical Equipment	9.49	JPN	Health and Social Work	11.88
26	USA	Chemicals and Chemical Products	9.47	USA	Hotels and Restaurants	11.81
27	USA	Hotels and Restaurants	9.42	USA	Real Estate Activities	10.95
28	USA	Real Estate Activities	9.26	DEU	Machinery, Nec	10.83
29	DEU	Machinery, Nec	8.54	USA	Chemicals and Chemical Products	10.75
30	JPN	Public Admin and Social Security	7.40	JPN	Public Admin and Social Security	10.46