Supporting Information for

Improving Subnational Input-Output Analyses Using Regional Trade Data: A Case-Study and Comparison

Meng Jiang,[†,‡] Lin Liu,[†,‡] Paul Behrens,[§,∥] Tao Wang,[†] Zhipeng Tang,[⊥] Dingjiang Chen,[†,∇] Yadong Yu,[#] Zijian Ren,[†] Shengjun Zhu,[○] Arnold Tukker,[,§,◆] and Bing Zhu[*,†,∇,∞]*

† Department of Chemical Engineering, Tsinghua University, Beijing, 100084, China;

§ Institute of Environmental Sciences (CML), Leiden University, Einsteinweg 2, 2333 CC, Leiden, The Netherlands;

∥ Leiden University College The Hague, 2595 DG, The Hague, The Netherlands;

⊥ Key Laboratory of Regional Sustainable Development Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China;

∇ Institute for Circular Economy, Tsinghua University, Beijing 100084, China;

School of Business, East China University of Science and Technology, Shanghai, 200237, China;

○ College of Urban and Environmental Sciences, Peking University, Beijing, 100871, China;

◆ The Netherlands Organisation for Applied Scientific Research TNO, 2595 DA Den Haag, The Netherlands

∞ Energy Program, International Institute for Applied Systems Analysis, Schlossplatz 1, Laxenburg, A-2361, Austria;

* To whom correspondence may be addressed. Email: bingzhu@mail.tsinghua.edu.cn or tukker@cml.leidenuniv.nl

‡ M.J. and L.L. contributed equally.

Count: 31 pages, 8 Figures and 11 Tables

Contents

Contents

S1 Supplement results

1.1 Four possible assumptions to distribute relative structures

As trade statistics only provide HS code, location information, assumptions have to be made to obtain the input-output relations of a given product. (For example, we know the amount of imported cars from Japan to Beijing based on customs statistics but we need to further allocate the input of cars to Beijing's every sector). Figure S1 gives a conceptual description of this process.

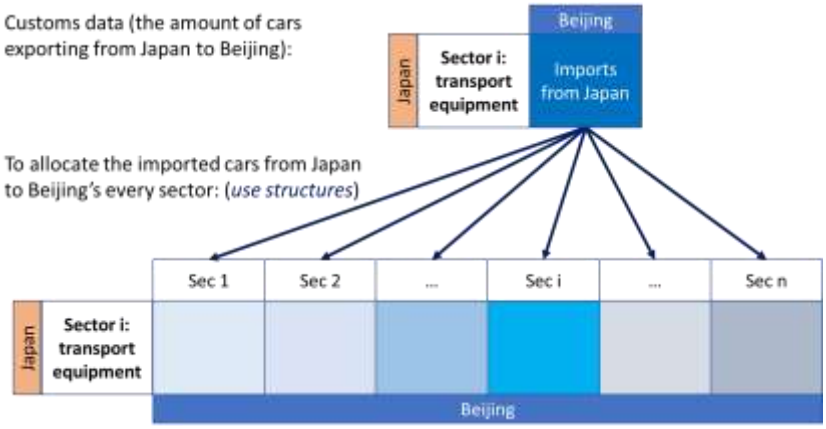

Figure S1. Conceptual chart of this allocation process

We conducted the comparative analysis on the four possible assumptions to estimate the use pattern of imported goods of a targeted province - a given sector of every province uses the import goods from the sector is similar to:

a) the use structure of the national economy (how do domestic cars are used in the national supply chain);
b) the use structure of the local economy (how do cars produced in Beijing are used in Beijing's local supply chain);
c) the use structure of input from other provinces but except local inputs (how do cars produced in other provinces, except Beijing, are used in Beijing's local supply chain); and,

d) the use structure of domestic inputs (how do domestic cars are used in Beijing's local supply chain).

Mathematically, we need to find a proper matrix whose elements would derive relative ratio for distribution:

(a)* $$z_{i,j}^{r,s} = z_{i,j}^{r} \cdot \frac{ts_i^{r,s}}{\sum_s ts_i^{r,s}} \quad \text{(eq1)}$$

(b)* $$z_{i,j}^{r,s} = z_{i,j}^{r} \cdot \frac{ts_i^{r,s}}{\sum_s ts_i^{r,s}} \cdot \frac{io\_t_{i,j}^{r,s}}{\sum_j io\_t_{i,j}^{r,s}} \quad \text{(eq2)}$$

(c)* $$z_{i,j}^{r,s} = z_{i,j}^{r} \cdot \frac{ts_i^{r,s}}{\sum_s ts_i^{r,s}} \cdot \frac{\sum_{s-1} io_{t_{i,j}}^{r,s}}{\sum_j \sum_{s-1} io_{t_{i,j}^{r,s}}} \quad \text{(eq3)}$$

(d)* $$z_{i,j}^{r,s} = z_{i,j}^{r} \cdot \frac{ts_i^{r,s}}{\sum_s ts_i^{r,s}} \cdot \frac{\sum_s io\_t_{i,j}^{r,s}}{\sum_j \sum_s io\_t_{i,j}^{r,s}} \quad \text{(eq4)}$$

*taking imports for example. It is similar to exports.

(b), (c) and (d) considering provincial-specifics. Their differences are spatial scopes of product/materials inputs: from the local only, from the domestic but except the local, and everything from the domestic. A comparative (sensitivity) analysis shows their differences in provincial MF (see Table S1) by comparing each one to (d). Results show (a) and (b) have larger deviations comparing with (c). (b) is based on the local economic system alone. It brings bias to metropolitans such as Shanghai and Beijing. The possible reason is their local extraction and manufacturing industries (structure) are not sufficient. Such developed provinces may highly rely on domestic or international imports. Following assumption (b), the distributional matrices could be very sparse and cause errors. (c) and (d) show very close results. The only difference is whether

we include the local economic system. (c) excludes the local processing while (d) presents a more comprehensive structure. If a province dominates an industry (for example, the steel industry in Hebei) in the national economy, it may also import raw / intermediated materials for manufacturing. Thus we can infer (c) might bring errors if the local industries of the targeted province are neglected. Finally, we recommend (d) since it considers the whole input from the domestic economy, avoiding errors extreme cases might bring.

Table S1. Sensitivity analysis of different assumption on the use pattern of imported goods of a targeted province

	MF per capita (a_simple)					MF per capita (b_local)					MF per capita (c_domestic without local)				
Prov	**MF**	**Bio**	**Ene**	**Me**	**NM**	**MF**	**Bio**	**Ene**	**Me**	**NM**	**MF**	**Bio**	**Ene**	**Me**	**NM**
Beijing	-2%	0%	-7%	0%	0%	1%	0%	1%	0%	1%	1%	0%	4%	-2%	0%
Tianjin	-1%	-1%	-2%	1%	-1%	1%	1%	1%	2%	1%	0%	-1%	0%	-1%	0%
Hebei	0%	-1%	-1%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%
Shanxi	0%	-1%	0%	0%	0%	0%	0%	0%	-1%	0%	0%	1%	0%	0%	0%
InnerMongolia	0%	-1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Liaoning	-1%	-5%	-2%	1%	0%	1%	-1%	4%	1%	0%	-1%	-3%	0%	-2%	0%
Jilin	-1%	-1%	-2%	0%	0%	0%	0%	2%	1%	0%	0%	0%	0%	-1%	0%
Heilongjiang	-1%	-1%	-2%	0%	0%	0%	0%	2%	0%	0%	0%	0%	-1%	-1%	0%
Shanghai	0%	2%	1%	3%	-2%	-7%	-3%	-11%	-18%	-4%	0%	-2%	0%	1%	0%
Jiangsu	0%	-2%	-1%	4%	0%	2%	0%	8%	3%	0%	0%	0%	0%	1%	0%
Zhejiang	1%	3%	2%	6%	1%	2%	-1%	8%	4%	1%	0%	2%	0%	4%	0%
Anhui	0%	-1%	0%	0%	0%	0%	0%	1%	0%	0%	0%	1%	0%	0%	0%
Fujian	-1%	-1%	-2%	-1%	-1%	0%	1%	-5%	2%	1%	0%	1%	0%	-3%	0%
Jiangxi	0%	0%	0%	0%	0%	0%	0%	0%	2%	0%	0%	0%	0%	-1%	0%
Shandong	-1%	-3%	-4%	-1%	0%	2%	-1%	14%	3%	0%	0%	3%	-1%	-1%	0%
Henan	0%	0%	-1%	0%	0%	0%	0%	0%	-1%	0%	0%	0%	0%	0%	0%
Hubei	0%	-1%	-1%	-1%	0%	0%	0%	3%	2%	0%	0%	-1%	-1%	1%	0%
Hunan	0%	-1%	-1%	0%	0%	0%	0%	-1%	1%	0%	0%	-1%	0%	0%	0%
Guangdong	5%	5%	4%	19%	3%	-1%	1%	-9%	2%	0%	0%	-1%	0%	0%	1%
Guangxi	0%	-1%	1%	2%	0%	0%	0%	-1%	1%	0%	0%	0%	1%	0%	0%
Hainan	0%	0%	0%	3%	0%	0%	0%	-3%	0%	0%	0%	1%	-1%	0%	0%
Chongqing	0%	0%	0%	2%	0%	0%	0%	-1%	1%	0%	0%	0%	0%	0%	0%

Sichuan	0%	0%	0%	3%	0%	0%	0%	0%	0%	0%	0%	0%	0%	2%	0%
Guizhou	0%	0%	0%	3%	0%	0%	0%	-1%	2%	0%	0%	0%	0%	0%	0%
Yunnan	0%	0%	0%	1%	0%	0%	0%	-1%	0%	0%	0%	0%	0%	0%	0%
Shaanxi	-1%	-2%	-1%	0%	0%	0%	1%	1%	0%	0%	0%	-1%	0%	0%	0%
Gansu	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%
Qinghai	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Ningxia	-1%	-1%	0%	1%	-1%	0%	0%	1%	0%	-1%	0%	0%	0%	0%	0%
Xinjiang	-1%	-3%	-1%	-1%	-1%	0%	0%	1%	1%	0%	0%	0%	0%	0%	0%

1.2 Calculating MF by three approaches

Table S2. The material footprint of nations calculated by EXIOBASE directly (million ton), in 2010

EXIOBASE	Country/region	MF*	Biomass	Fossil Fuels	Metal	Nonmetal
1	Austria	218	52	34	12	121
2	Belgium	326	80	56	21	169
3	Bulgaria	99	22	36	13	28
4	Cyprus	26	4	4	1	17
5	Czech Republic	212	44	63	10	95
6	Germany	1,840	401	427	99	914
7	Denmark	135	39	26	7	64
8	Estonia	22	6	3	1	13
9	Spain	859	219	131	48	461
10	Finland	163	51	32	10	69
11	France	1,258	418	188	61	591
12	Greece	272	49	99	11	112
13	Croatia	50	16	9	2	23
14	Hungary	145	34	49	5	56
15	Ireland	173	35	28	11	100
16	Italy	1,210	272	275	60	603
17	Lithuania	49	16	12	2	20
18	Luxembourg	23	7	4	2	11
19	Latvia	31	10	4	1	17
20	Malta	10	1	3	1	4
21	Netherlands	426	101	105	30	190
22	Poland	619	143	149	52	275
23	Portugal	201	46	22	7	127
24	Romania	256	77	57	9	112
25	Sweden	279	75	35	33	136

26	Slovenia	42	9	10	2	21
27	Slovak Republic	99	19	30	5	45
28	United Kingdom	1,215	313	254	71	577
29	United States	8,175	2,061	1,946	867	3,301
30	Japan	1,800	344	377	161	918
31	Canada	1,240	266	352	145	478
32	South Korea	1,026	151	227	103	544
33	Brazil	3,386	2,159	238	279	710
34	India	3,764	2,119	853	263	529
35	Mexico	1,141	398	179	164	400
36	Russian Federation	1,812	466	583	136	627
37	Australia	993	264	227	247	256
38	Switzerland	180	46	28	16	91
39	Turkey	866	231	166	40	429
40	Chinese Taiwan	540	96	156	86	202
41	Norway	215	41	60	13	102
42	Indonesia	2,023	640	246	630	506
43	South Africa	494	150	136	90	118
44	RoW Asia and Pacific	5,126	1,586	851	421	2,267
45	RoW America	3,574	1,270	382	884	1,038
46	RoW Europe	708	208	145	83	272
47	RoW Africa	3,708	1,981	261	244	1,222
48	RoW Middle East	3,519	654	584	213	2,068
49	China, Mainland	21,622	2,872	3,550	1,651	13,549

*Note the domestic extraction data of mainland China are replaced by our newly developed one. And the sectors are aggregated to 48. (indicated in Table S11) aligning with the subnational model.

Table S3. The material footprint of nations calculated by the direct-linking approach and the comparison to results from the direct EXIOBASE, in 2010

		Material footprint (million ton) by the direct-linking approach*					The percentage change between the direct-linking and EXIOBASE				
	Country /region	MF	Biomass	Fossil Fuels	Metal	Non-metal	MF	Biomass	Fossil Fuels	Metal	Non-metal
1	Austria	216	52	33	12	118	-1%	0%	0%	2%	-2%
2	Belgium	320	80	56	21	164	-2%	0%	-1%	1%	-3%
3	Bulgaria	99	22	36	13	28	0%	0%	0%	2%	-1%
4	Cyprus	26	4	4	1	17	0%	0%	0%	1%	0%
5	Czech Republic	211	44	62	11	94	0%	0%	0%	2%	-1%
6	Germany	1,797	399	422	99	877	-2%	0%	-1%	-1%	-4%

7	Denmark	134	38	26	7	63	-1%	-1%	0%	1%	-2%
8	Estonia	22	6	3	1	12	-1%	0%	0%	0%	-1%
9	Spain	843	218	130	49	446	-2%	0%	-1%	1%	-3%
10	Finland	162	51	32	11	68	-1%	0%	-1%	0%	-2%
11	France	1,226	417	185	61	563	-3%	0%	-1%	0%	-5%
12	Greece	268	49	99	11	109	-2%	0%	0%	-1%	-3%
13	Croatia	50	16	9	2	23	0%	0%	-1%	-1%	-1%
14	Hungary	143	34	49	5	54	-1%	0%	0%	0%	-3%
15	Ireland	170	35	28	11	97	-2%	0%	-1%	0%	-3%
16	Italy	1,199	271	274	61	593	-1%	0%	0%	1%	-2%
17	Lithuania	49	16	12	2	19	0%	0%	0%	1%	-1%
18	Luxembourg	23	7	4	2	10	-1%	0%	0%	1%	-2%
19	Latvia	31	10	4	1	16	-2%	0%	0%	1%	-3%
20	Malta	10	1	3	1	4	0%	0%	3%	-1%	-2%
21	Netherlands	412	100	104	30	177	-3%	0%	-1%	0%	-7%
22	Poland	614	143	148	53	270	-1%	0%	0%	1%	-2%
23	Portugal	200	46	22	7	125	-1%	0%	0%	1%	-2%
24	Romania	254	77	57	10	110	-1%	0%	0%	1%	-1%
25	Sweden	282	75	35	33	140	1%	0%	-1%	0%	3%
26	Slovenia	41	10	10	2	21	-2%	0%	-1%	0%	-4%
27	Slovak Republic	97	19	29	5	44	-2%	0%	0%	2%	-3%
28	United Kingdom	1,159	311	252	71	525	-5%	-1%	-1%	0%	-9%
29	United States	7,958	2,047	1,921	866	3,125	-3%	-1%	-1%	0%	-5%
30	Japan	1,739	338	361	161	879	-3%	-2%	-4%	0%	-4%
31	Canada	1,220	265	349	145	460	-2%	0%	-1%	0%	-4%
32	South Korea	988	150	215	104	519	-4%	-1%	-5%	1%	-5%
33	Brazil	3,373	2,161	237	282	693	0%	0%	-1%	1%	-2%
34	India	3,718	2,119	852	265	482	-1%	0%	0%	1%	-9%
35	Mexico	1,129	398	178	165	388	-1%	0%	0%	0%	-3%
36	Russian Federation	1,792	466	581	136	609	-1%	0%	0%	0%	-3%
37	Australia	967	263	225	248	232	-3%	0%	-1%	0%	-9%
38	Switzerland	177	46	28	16	88	-2%	0%	-1%	1%	-3%
39	Turkey	854	231	164	40	419	-1%	0%	-1%	0%	-2%
40	Chinese Taiwan	539	96	157	86	199	0%	0%	0%	1%	-1%
41	Norway	215	40	60	13	102	0%	-1%	-1%	0%	0%
42	Indonesia	2,008	639	247	631	491	-1%	0%	0%	0%	-3%
43	South Africa	496	150	137	91	118	0%	0%	1%	1%	-1%
44	RoW Asia and Pacific	4,947	1,584	840	425	2,098	-3%	0%	-1%	1%	-7%
45	RoW America	3,559	1,271	380	913	995	0%	0%	-1%	3%	-4%

46	RoW Europe	711	209	145	88	268	0%	1%	0%	6%	-1%
47	RoW Africa	3,687	1,982	260	246	1,199	-1%	0%	-1%	1%	-2%
48	RoW Middle East	3,467	652	578	213	2,024	-1%	0%	-1%	0%	-2%
49	China, Mainland	22,573	2,904	3,647	1,600	14,422	4%	1%	3%	-3%	6%

*Note the domestic extraction data of mainland China are replaced by our newly developed one

Table S4. The material footprint of nations calculated by the TSA approach and the comparison to results from the direct EXIOBASE, in 2010

		Material footprint (million ton) by the TSA approach*					The percentage change between the TSA and EXIOBASE				
	Country /region	MF	Biomass	Fossil Fuels	Metal	Non-metal	MF	Biomass	Fossil Fuels	Metal	Non-metal
1	Austria	215	51	33	12	119	-2%	-1%	-2%	-1%	-3%
2	Belgium	318	80	55	20	163	0%	0%	0%	0%	-1%
3	Bulgaria	99	22	36	13	28	-1%	0%	-1%	-1%	-1%
4	Cyprus	26	4	4	1	17	-1%	0%	-1%	-2%	-2%
5	Czech Republic	209	44	62	10	93	-2%	-1%	-1%	-2%	-3%
6	Germany	1,802	399	421	97	886	-1%	0%	-1%	-1%	-2%
7	Denmark	133	39	26	7	62	-1%	0%	-1%	-1%	-1%
8	Estonia	22	6	3	1	12	-2%	0%	-1%	-1%	-2%
9	Spain	846	218	129	47	451	-1%	0%	-1%	-1%	-3%
10	Finland	161	51	32	10	67	-2%	0%	-2%	-2%	-3%
11	France	1,237	417	185	60	576	-1%	0%	0%	-1%	-2%
12	Greece	269	49	99	11	110	-1%	0%	-1%	-2%	-2%
13	Croatia	49	16	9	2	22	-1%	0%	0%	-2%	-2%
14	Hungary	143	34	49	5	55	-1%	0%	-1%	-1%	-2%
15	Ireland	171	35	28	11	98	-2%	0%	-1%	-2%	-2%
16	Italy	1,191	270	272	59	589	-1%	0%	0%	-1%	-1%
17	Lithuania	49	16	12	2	19	-2%	0%	-1%	-1%	-3%
18	Luxembourg	23	7	4	2	10	-1%	0%	-1%	-1%	-1%
19	Latvia	31	10	4	1	16	-2%	0%	-2%	-1%	-3%
20	Malta	9	1	3	1	4	-2%	0%	-1%	-1%	-4%
21	Netherlands	417	100	104	30	183	-1%	0%	-1%	-1%	-2%
22	Poland	613	143	148	52	270	-1%	0%	-1%	-1%	-1%
23	Portugal	200	45	22	6	126	-1%	0%	0%	-1%	-1%
24	Romania	254	77	57	9	111	-2%	0%	-2%	-1%	-3%
25	Sweden	274	75	34	33	132	-1%	0%	-1%	-2%	-2%
26	Slovenia	42	9	10	2	21	-1%	0%	-1%	-1%	-2%

27	Slovak Republic	97	19	29	5	44	-3%	-1%	-2%	-2%	-5%
28	United Kingdom	1,179	311	250	70	548	-2%	-1%	-2%	-1%	-4%
29	United States	7,998	2,050	1,916	857	3,175	-3%	-1%	-2%	-2%	-5%
30	Japan	1,743	340	369	158	876	-1%	0%	-1%	-1%	-3%
31	Canada	1,223	265	349	144	465	-3%	-1%	-2%	-1%	-4%
32	South Korea	995	150	223	102	520	0%	0%	-1%	0%	-2%
33	Brazil	3,371	2,158	236	278	699	-1%	0%	-1%	-1%	-5%
34	India	3,732	2,118	849	262	503	-1%	0%	-1%	0%	-2%
35	Mexico	1,130	397	177	164	392	-1%	0%	0%	-1%	-2%
36	Russian Federation	1,796	465	580	135	615	-2%	0%	-1%	0%	-6%
37	Australia	974	263	224	246	242	-2%	0%	-2%	-1%	-2%
38	Switzerland	178	46	27	16	89	-1%	0%	-1%	-1%	-1%
39	Turkey	857	231	164	39	423	-1%	0%	0%	0%	-1%
40	Chinese Taiwan	536	96	156	85	200	-2%	-1%	-1%	-1%	-4%
41	Norway	210	40	60	12	98	-1%	0%	-1%	0%	-2%
42	Indonesia	2,009	640	245	630	495	0%	0%	0%	0%	-1%
43	South Africa	493	150	136	90	117	-3%	0%	-5%	-2%	-5%
44	RoW Asia and Pacific	4,965	1,579	813	412	2,162	-1%	0%	-2%	0%	-3%
45	RoW America	3,536	1,268	377	882	1,010	0%	0%	0%	0%	-1%
46	RoW Europe	704	207	144	83	269	-1%	0%	-1%	0%	-1%
47	RoW Africa	3,687	1,980	258	243	1,206	-1%	0%	-1%	-1%	-2%
48	RoW Middle East	3,470	651	576	210	2,033	4%	2%	4%	3%	4%
49	China, Mainland	22,406	2,918	3,695	1,696	14,098	1%	0%	-1%	-6%	2%

*Note the domestic extraction data of mainland China are replaced by our newly developed one

1.3 Sensitivity analysis on trade in services

CCTS data only covers trades in products, not trades in services, however, we assume that the amount of trade in services is highly associated with trade in goods among provinces. We allocated the service-trade in importing/exporting matrices by using the proxy of the aggregated trade structure of products of each region. It means a province imports more commodities would purchase more relevant services with the same trading partner[1]. To test the influence of trades in services, we create an extreme case, setting the services trading matrices to zero in a sensitivity

analysis. Results show trade in services have a low impact on material accounting that the average change of provincial MF is -0.16% comparing with our approach.

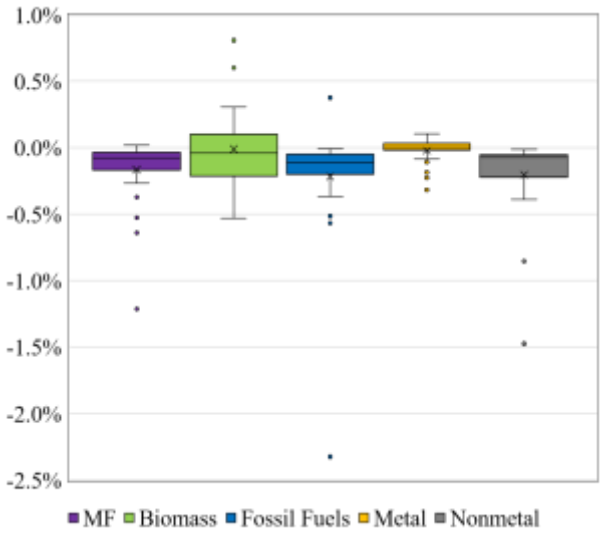

Figure S2. Box-and-whisker plots of the differences between the provincial MF of 23 types of resources calculated by the service-sector-in-trade-removed model and distributed as a product-trade-structure model. The horizontal line is median, the cross is mean, the interquartile range is equal to the difference between the 75th and 25th percentiles, the maximum length of whiskers is 1.5 times the interquartile range (IQR); single points are outliners. Data are for 2010.

1.4 Aggregated impacts at the national level, for biomass, fossil fuels, metal, and nonmetallic minerals

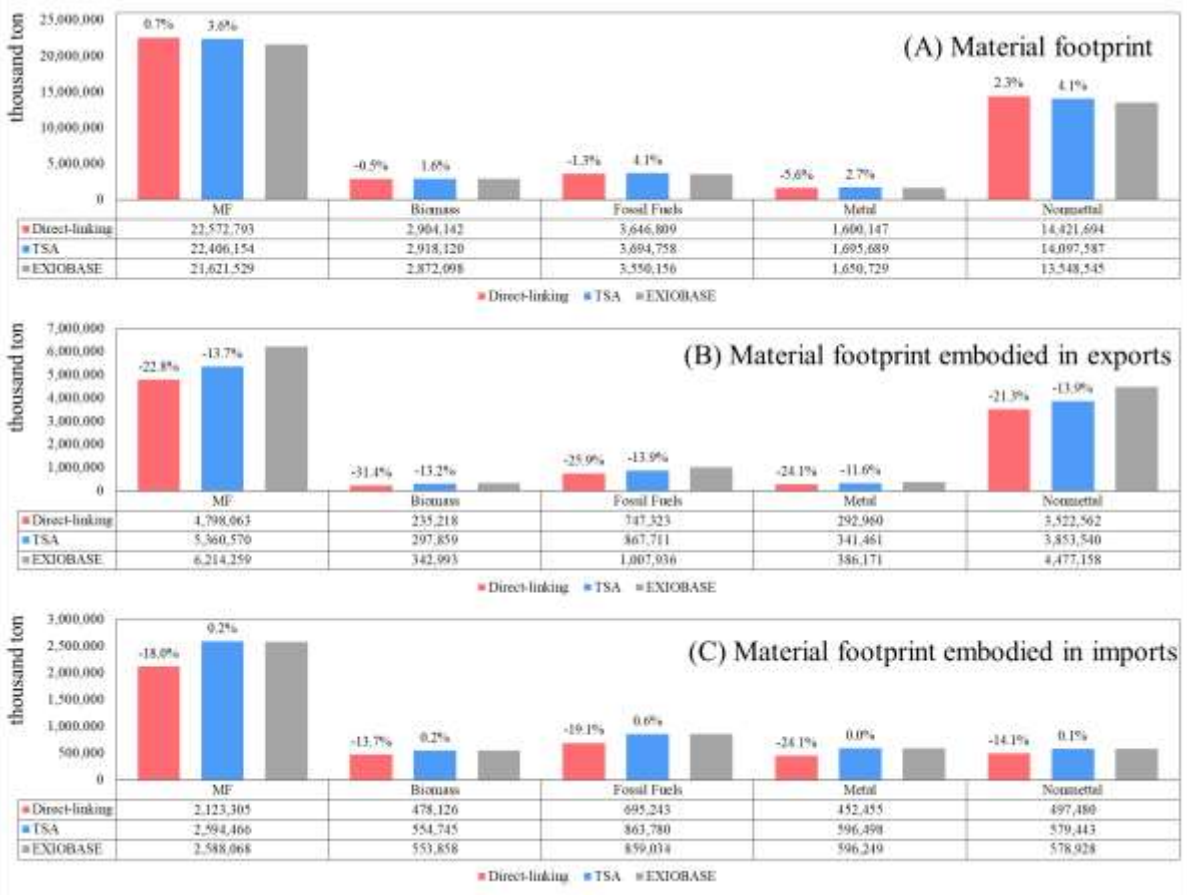

Figure S3. Comparison results: (A) material footprint (MF), (B) MF embodied in exports, and (C) MF embodied in imports of China. The results are calculated by the direct-linking approach (to nest the inter-provincial IOT in EXIOBASE by regional trade data) in red, TSA approaches (to nest the inter-provincial IOT in EXIOBASE by proportionality assumption) in blue and EXIOBASE directly (a national-level GMRIO) in grey. The percentage changes comparing to the direct EXIOBASE approach are noted respectively. Data are for 2010.

1.5 Statistical measures on MF differences: TSA versus the direct-linking

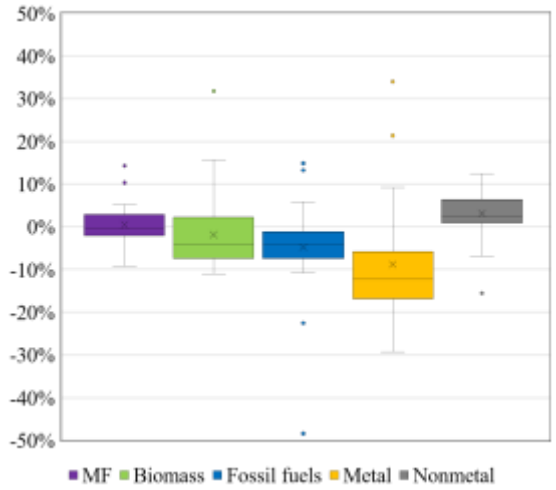

Figure S4. Box-and-whisker plots of the differences (in percentage changes) between the results calculated from the TSA-linking and the direct-linking. The horizontal line is median; the cross is mean; the interquartile range is equal to the difference between the 75th and 25th percentiles; the maximum length of whiskers is 1.5 times the interquartile range; single points are outliners. Data are for 2010.

Table S5. Statistical measures describing the differences (percentage changes) between the MF results calculated from the TSA and direct-linking

	MF	Biomass	Fossil fuels	Metals	Nonmetals
Count	30.0	30.0	30.0	30.0	30.0
Min	-9.2	-11.1	-48.4	-29.3	-15.5
25% quartile	-1.8	-6.9	-7.2	-16.4	1.0
Median	-0.5	-4.2	-4.2	-12.3	2.5
75% quartile	2.5	1.6	-1.7	-6.2	6.3
Max	14.2	31.8	14.9	34.0	12.5

Range	23.4	42.8	63.3	63.2	28.0
Interquartile range	4.4	8.5	5.5	10.2	5.3
Mean	0.5	-1.9	-4.7	-8.8	3.1
Standard deviation	4.4	8.7	10.7	12.8	5.2

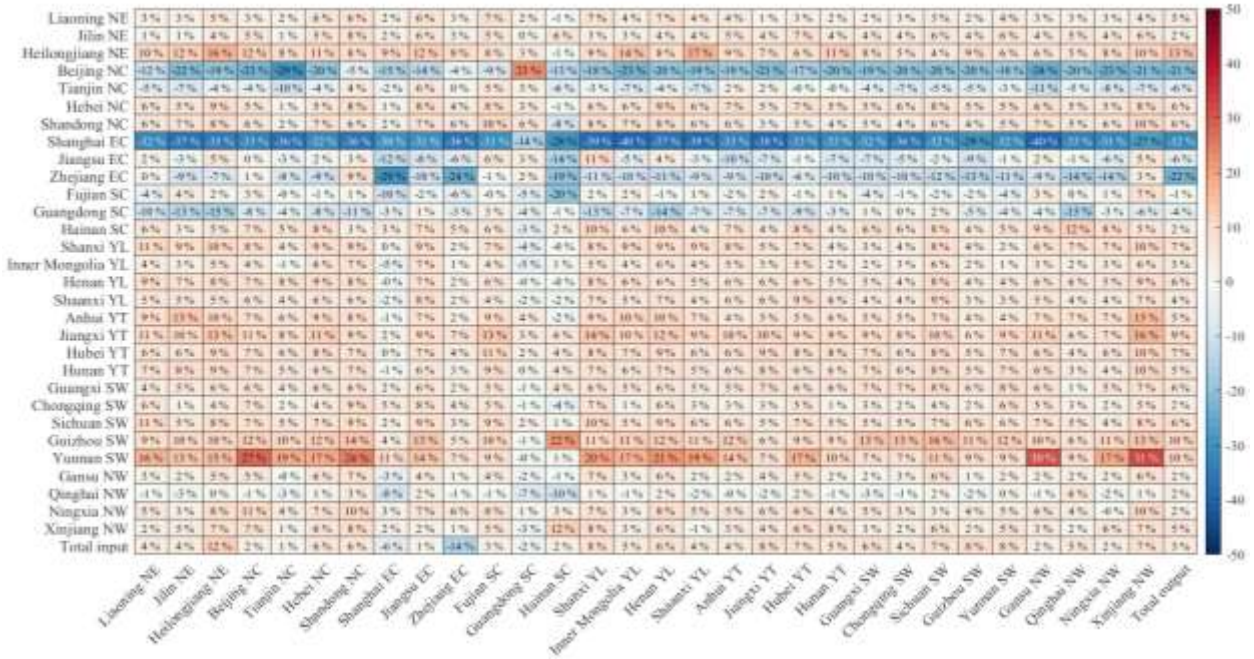

Figure S5. Heatmap showing the percentage of changes in the interprovincial flows.

To note that Shanghai is an outlier case whose local extraction is extremely small (0.3% of the national total) but replies on inter-provincial and international imports to a very high degree (99.6%). Minor changes in Shanghai may lead to a large relative change as it is shown in the row vector of Shanghai. Data are for 2010.

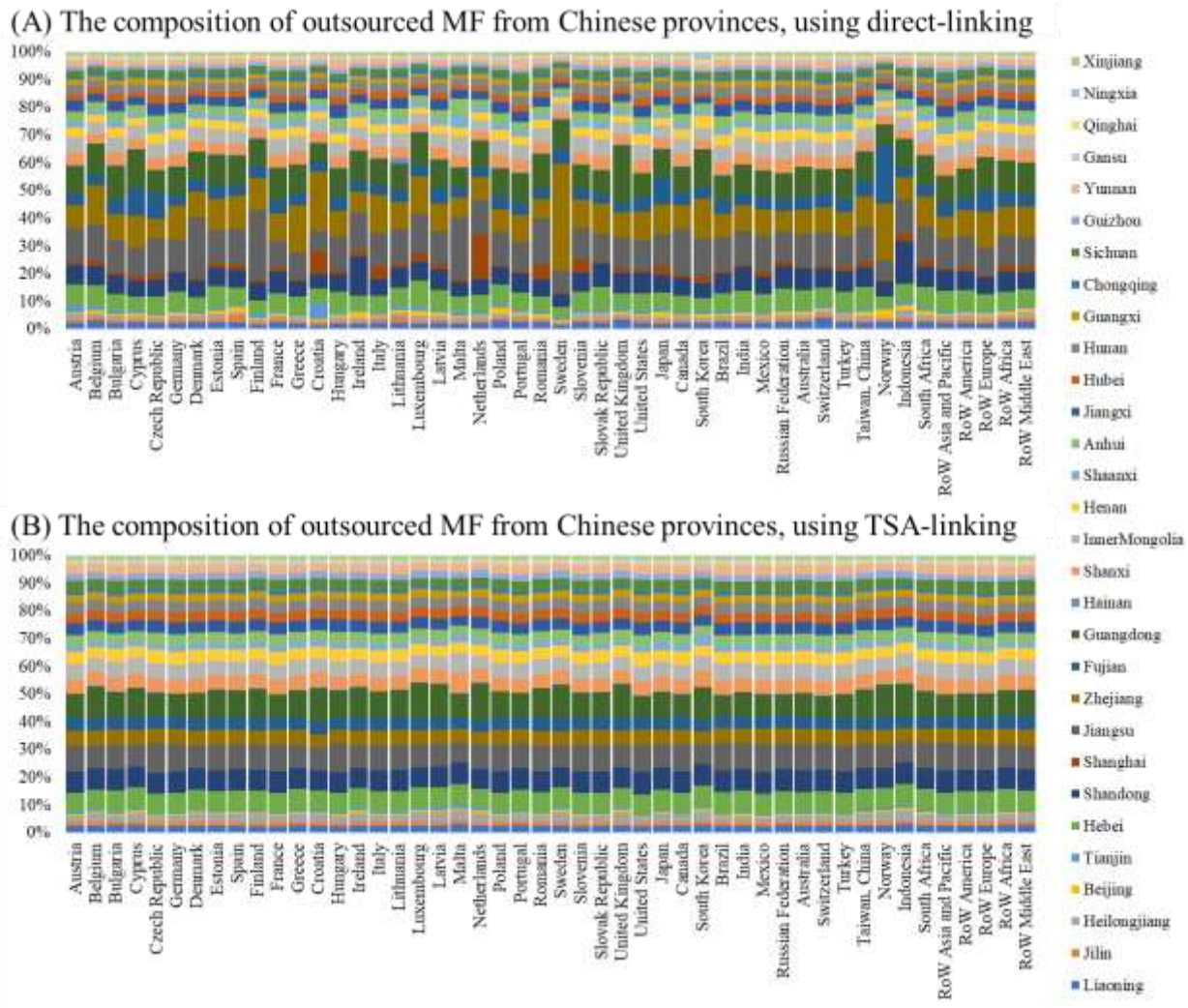

Figure S6. Outsourced origin of the MF for different regions in percentages for each province. Results derived from direct-linking and the TSA-linking are presented in (A) and (B) respectively.

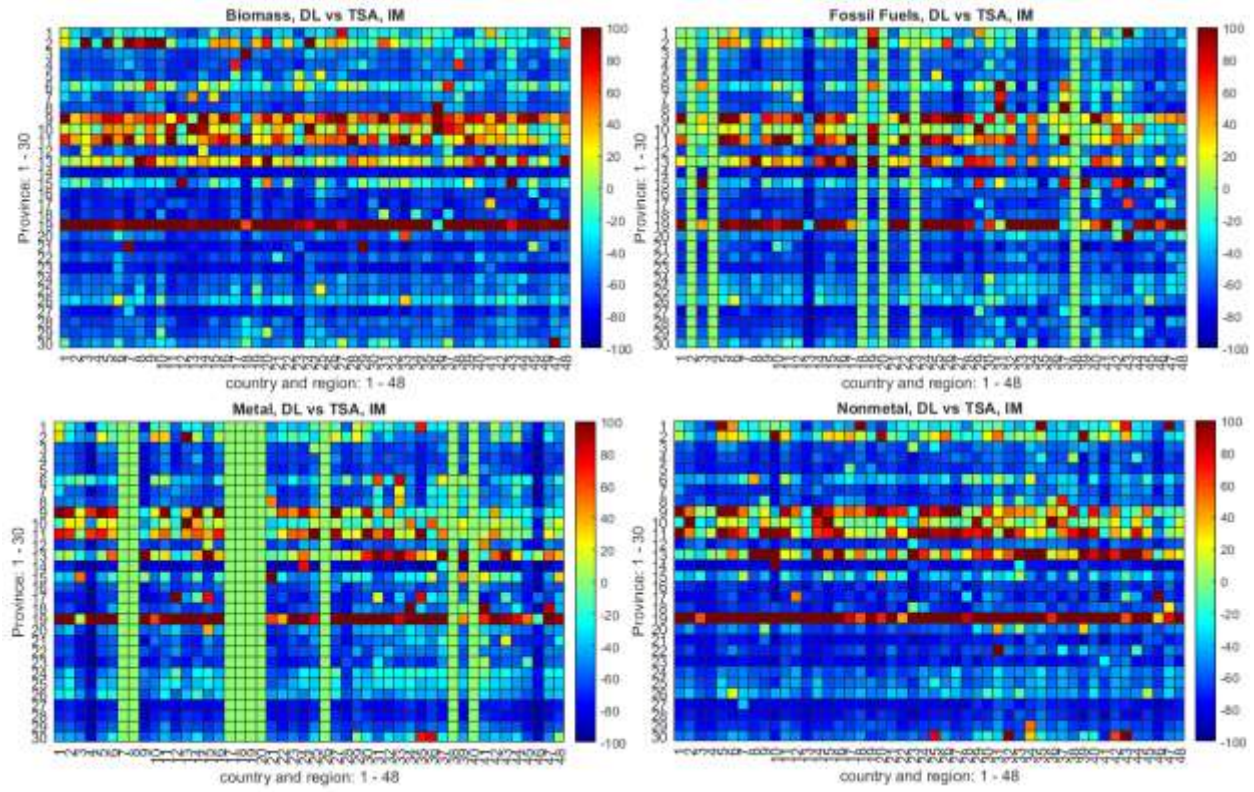

Figure S7. The difference in material embodied in imports among countries/regions and provinces between the direct linking and TSA approach. Heatmap showing the percentage of changes (the direct linking vs. TSA approach). Provinces and countries/regions number are noted in Table S9.

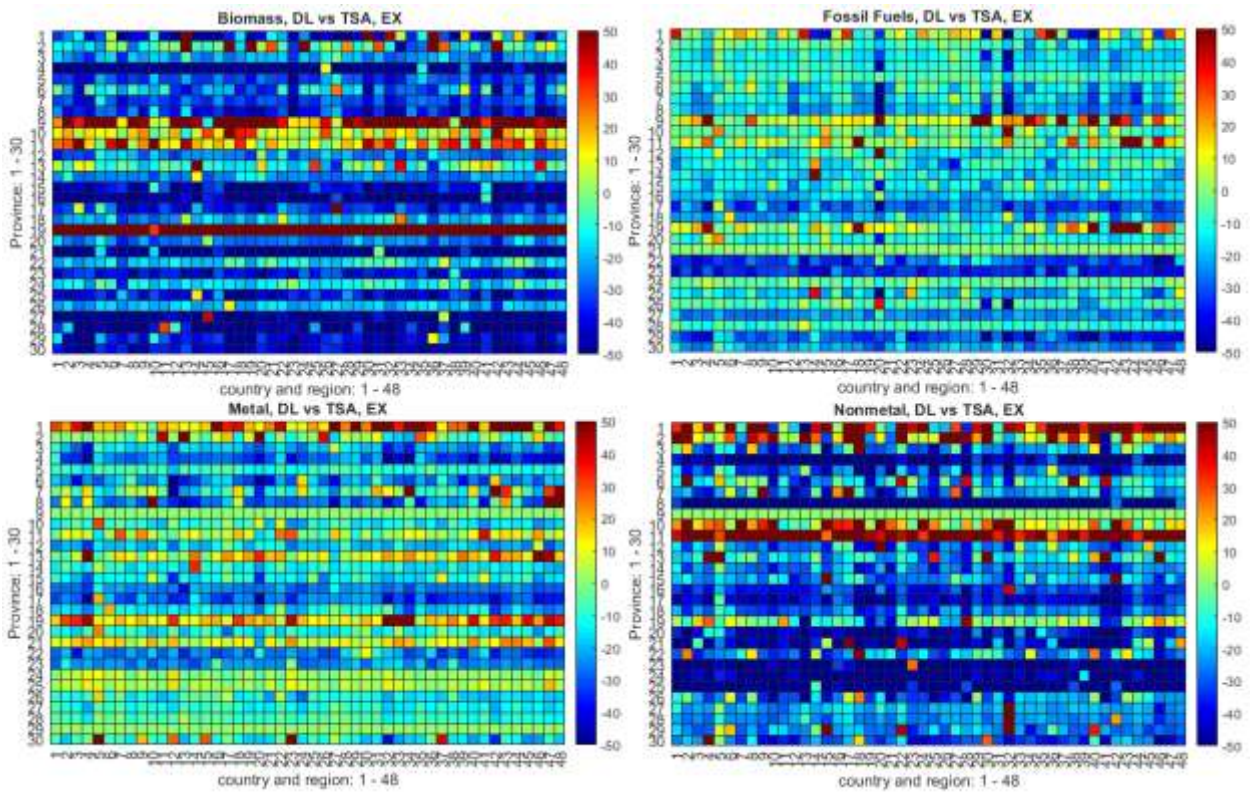

Figure S8. The difference in material embodied in exports among countries/regions and provinces between the direct linking and TSA approach. Heatmap showing the percentage of changes (the direct linking vs. TSA approach). Provinces and countries/regions number are noted in Table S9.

S2 Method demonstration and data sources

2.1 Material extensions

We constructed DE data for each province in China. Our provincial DE database followed the category system recommended by Eurostat[2] and UN Environment IRP[3, 4].

Table S6. Resource classifications

Category	Sub-category	Types
A.1 Biomass		
	A.1.1 Crops (excluding fodder crops)	
		A.1.1.1 Cereals
		A.1.1.2 Fruits, roots, and tubers
		A.1.1.3 Oil-bearing crops
		A.1.1.4 Sugar crops
		A.1.1.5 Cotton
		A.1.1.6 Other crops n.e.c.
	A.1.2 Crops residues (used), fodder crops and grazed biomass	
		A.1.2.1 Crops residues (used)
		A.1.2.2 Fodder crops and grazed biomass
	A.1.3 Wood	
	A.1.4 Wild fish catch	
A.2 Metal ores		
	A.2.1 Iron	
	A.2.2 Non-ferrous metal	
		A.2.2.1 Copper-gross ore
		A.2.2.2 Nickel-gross ore
		A.2.2.3 Bauxite and other aluminum-gross ore
		A.2.2.4 Gold and silver-gross ore
		A.2.2.5 Lead, zinc and tin-gross ore
		A.2.2.6 Other n.e.c.-gross ore
A.3 Non-metallic minerals		

	A.3.1 Non-metallic ores	
		A.3.1.1 Marble, granite, sandstone, porphyry, basalt, other ornamental or building stone (excluding slate)
		A.3.1.2 Chalk and dolomite
		A.3.1.3 Slate
		A.3.1.4 Limestone and gypsum
	A.3.2 Soil and gravel	
		A.3.2.1 Sand and gravel
		A.3.2.2 Clays and kaolin
	A.3.3 Chemical and fertilizer minerals and other n.e.c.	
		A.3.3.1 Chemical minerals and other n.e.c.
		A.3.3.2 Salt
A.4 Fossil energy materials/carriers		
	A.4.1 Coal	
	A.4.2 Petroleum	
	A.4.3 Natural gas	
	A.4.4 Other unconventional oil and gas	

Table S7. Resource grouping classification

No	Resource group	Detailed type of resource
1	Cereal	A.1.1.1 Cereals
2	Nuts, vegetables, fruits	A.1.1.2 Fruits, roots, and tubers
3	Oil-bearing crops	A.1.1.3 Oil-bearing crops
4	Sugar crops	A.1.1.4 Sugar crops
5	Fibers	A.1.1.5 Cotton;
6	Other crops	A.1.1.6 Other crops n.e.c.; A.1.2.1 Crops residues (used);
7	Animal husbandry	A.1.2.2 Fodder crops and grazed biomass
8	Forestry	A.1.3 Wood
9	Fishery	A.1.4 Wild fish catch
10	Coal	A.4.1 Coal
11	Oil	A.4.2 Petroleum
12	Natural gas	A.4.3 Natural gas

13	Other petroleum and gaseous materials	A.4.4 Other unconventional oil and gas
14	Iron ores	A.2.1 Iron
15	Copper	A.2.2.1 Copper-gross ore
16	Nickel	A.2.2.2 Nickel-gross ore
17	Bauxite	A.2.2.3 Bauxite and other aluminum-gross ore
18	Precious metal	A.2.2.4 Gold and silver-gross ore
19	Lead, zinc, tin	A.2.2.5 Lead, zinc and tin-gross ore
20	Other non-ferrous metal	A.2.2.6 Other n.e.c.-gross ore
21	Stone	A.3.1.1 Marble, granite, sandstone, porphyry, basalt, other ornamental or building stone (excluding slate); A.3.1.2 Chalk and dolomite; A.3.1.3 Slate; A.3.1.4 Limestone and gypsum
22	Quarrying of sand and clay	A.3.2.1 Sand and gravel; A.3.2.2 Clays and kaolin
23	Chemical, fertilizer and salt, other quarrying	A.3.3.1 Chemical minerals and other n.e.c.; A.3.3.2 Salt

Table S8. Calculation/estimation method and sources of underlying data on material extractions.

Types	**Method**	**Underlying data source**
A.1.1.1 Cereals	DE based on directly available statistical data per province (or with simple conversion)	China Agriculture Yearbook[5]
A.1.1.2 Fruits, roots, and tubers		China Agriculture Yearbook[5], China Rural Statistical Yearbook[6]
A.1.1.3 Oil-bearing crops		China Rural Statistical Yearbook[6]
A.1.1.4 Sugar crops		China Rural Statistical Yearbook[6]
A.1.1.5 Cotton		China Agriculture Yearbook[5], China Rural Statistical Yearbook[6]
A.1.1.6 Other crops n.e.c.		China Rural Statistical Yearbook[6]
A.1.2.1 Crops residues (used)	Estimation based on the method recommended by Eurostat in its economy-wide Material Flow Analysis (EW-MFA) guide	China Agriculture Yearbook[5], coefficients come from EU Directive[2]
A.1.2.2 Fodder crops and grazed biomass		China Agriculture Yearbook[5], coefficients come from EU Directive[2]

A.1.3 Wood	DE based on directly available statistical data per province (or with simple conversion)	China Forestry Yearbook, coefficients come from EU Directive[2]
A.1.4 Wild fish catch		China Rural Statistical Yearbook[6]
A.2.1 Iron		China Industry Economy Statistical Yearbook[7]
A.2.2.1 Copper-gross ore	Measures and estimation based on national projects. Described in our previous study[8]	China Nonferrous Metals Industry Yearbook[9]; national projects[10, 11]
A.2.2.2 Nickel-gross ore		China Nonferrous Metals Industry Yearbook[9]; national projects[10, 11]
A.2.2.3 Bauxite and other aluminum-gross ore		China Nonferrous Metals Industry Yearbook[9], Statistical Yearbooks of provinces; national projects[10, 11]
A.2.2.4 Gold and silver-gross ore		China Nonferrous Metals Industry Yearbook[9]; national projects[10, 11]
A.2.2.5 Lead, zinc and tin-gross ore		China Nonferrous Metals Industry Yearbook[9]; national projects[10, 11]
A.2.2.6 Other n.e.c.-gross ore		China Nonferrous Metals Industry Yearbook[9]; national projects[10, 11]
A.3.1.1 Marble, granite, sandstone, porphyry, basalt, other ornamental or building stone (excluding slate)	DE based on directly available statistical data per province (or with simple conversion)	China Mining Yearbook[12]
A.3.1.2 Chalk and dolomite		China Mining Yearbook[12]
A.3.1.3 Slate		China Mining Yearbook[12]
A.3.1.4 Limestone and gypsum	Estimation based on the method recommended by Eurostat in its economy-wide Material Flow Analysis (EW-MFA) guide	China Cement Almanac[13], China Statistical Yearbook of the Tertiary Industry[7]
A.3.2.1 Sand and gravel		China Cement Almanac[13], China Statistical Yearbook of the Tertiary Industry[7]
A.3.2.2 Clays and kaolin		China Building Materials Industry Yearbook[7], coefficients from Wang et al., 2014 [14]

A.3.3.1 Chemical minerals and other n.e.c.	DE based on directly available statistical data per province (or with simple conversion)	China Industry Economy Statistical Yearbook[7], China Mining Yearbook[12]
A.3.3.2 Salt		China Mining Yearbook[12]
A.4.1 Coal		China Energy Statistical Yearbook[15], Statistical Yearbooks of province
A.4.2 Petroleum		China Energy Statistical Yearbook[15]
A.4.3 Natural gas		China Energy Statistical Yearbook[15]
A.4.4 Other unconventional oil and gas		China Energy Statistical Yearbook[15]

The allocation of extensions to the sectors of China's economy is a straightforward one-to-one exercise since most of the material items entering the economic system are from the extractive (harvesting) industries[16].

2.2 The embedded EEIO model

Table S9. Regions included in the model

No.	Country and region	No.	Provinces in Mainland China
1	Austria	1	Beijing
2	Belgium	2	Tianjin
3	Bulgaria	3	Hebei
4	Cyprus	4	Shanxi
5	Czech Republic	5	Inner Mongolia
6	Germany	6	Liaoning
7	Denmark	7	Jilin
8	Estonia	8	Heilongjiang
9	Spain	9	Shanghai
10	Finland	10	Jiangsu
11	France	11	Zhejiang
12	Greece	12	Anhui
13	Croatia	13	Fujian

14	Hungary	14	Jiangxi
15	Ireland	15	Shandong
16	Italy	16	Henan
17	Lithuania	17	Hubei
18	Luxembourg	18	Hunan
19	Latvia	19	Guangdong
20	Malta	20	Guangxi
21	Netherlands	21	Hainan
22	Poland	22	Chongqing
23	Portugal	23	Sichuan
24	Romania	24	Guizhou
25	Sweden	25	Yunnan
26	Slovenia	26	Shaanxi
27	Slovak Republic	27	Gansu
28	United Kingdom	28	Qinghai
29	United States	29	Ningxia
30	Japan	30	Xinjiang
31	Canada		
32	South Korea		
33	Brazil		
34	India		
35	Mexico		
36	Russian Federation		
37	Australia		
38	Switzerland		
39	Turkey		
40	Chinese Taiwan		
41	Norway		
42	Indonesia		
43	South Africa		
44	RoW Asia and Pacific		
45	RoW America		
46	RoW Europe		
47	RoW Africa		
48	RoW Middle East		

We grouped 30 provinces into 8 clusters following government recommendations (by the Division of Development Strategy and Regional Economy of Development Research Center of the State Council of China)[17]. It is shown in Table S5. Tibet, Hong Kong, Macao, and Taiwan are not included yet given to data availability and methodological consistency.

Since we reconstruct the China-related matrices in a GMRIO, EXIOBASE, such modification of IOTs may result in an unbalanced final table for which bi-proportional adjustments (i.e. RAS or other methods) are often employed to rebalance[18]. Wiebe et al.[18], found by using the RASed and non-RASed versions of MRIO will not cause significant differences in footprint assessment. Hence to exclude the possible influences that might be introduced by bi-proportional adjustments (i.e. RAS or other methods), we skip RAS procedure for all comparisons in this study.

Table S10. Grouping criteria of provinces

Grouped region	Province
Northeast	Liaoning, Jilin, Heilongjiang
North Coast	Beijing, Tianjin, Hebei, Shandong,
East Coast	Shanghai, Jiangsu, Zhejiang
South Coast	Fujian, Guangdong, Hainan
Yellow River Midstream	Shanxi, Inner Mongolia, Henan, Shaanxi
Yangtze River Midstream	Anhui, Jiangxi, Hubei, Hunan
Southwest	Guangxi, Chongqing, Sichuan, Guizhou, Yunnan
Northwest	Gansu, Qinghai, Ningxia, Xinjiang

Table S11. Sector classification in the model

No	Sectors
1	Cereal
2	Nuts, vegetables, fruits

3	Oil-bearing crops
4	Sugar crops
5	Fibers
6	Other crops
7	Animal husbandry
8	Forestry
9	Fishery
10	Coal
11	Oil
12	Natural gas
13	Other petroleum and gaseous materials
14	Iron ores
15	Copper
16	Nickel
17	Bauxite
18	Precious metal
19	Lead, zinc, tin
20	Other non-ferrous metal
21	Stone
22	Quarrying of sand and clay
23	Chemical, fertilizer and salt, other quarrying
24	Manufacture of foods and tobacco
25	Manufacture of textiles
26	Manufacture of textile wearing apparel, footwear, caps, leather, fur, feather(down) and its product
27	Processing of timbers and manufacture of furniture
28	Papermaking, printing, and manufacture of articles for culture, education and sports activities
29	Processing of petroleum, coking, processing of nuclear fuel
30	Chemical industry
31	Manufacture of nonmetallic mineral products
32	Smelting and rolling of metals
33	Manufacture of metal products
34	Manufacture of general-purpose and special-purpose machinery
35	Manufacture of transport equipment
36	Manufacture of electrical machinery and equipment
37	Manufacture of communication equipment, computer, and other electronic equipment
38	Manufacture of measuring instrument and machinery for cultural activity & office work
39	Other manufacture

40	Production and supply of electric power and heat power
41	Production and distribution of gas and water
42	Construction
43	Traffic, transport, and storage
44	Wholesale and retail trades
45	Hotels and catering services
46	Leasing and business services
47	Research and experimental development
48	Other services

2.3 Data availability

EXIOBASE[16] is available at https://www.exiobase.eu.

China's Provincial MRIO is available two ways, either:

- from the data on the CD attached to the official statistical books: "W. Liu, Z. Tang, J. Chen, B. Yang (2014) China's interregional input-output tables between 30 provinces in 2010. (China Statistics Press, Beijing)"[19];
- or, upon request to The Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences (mriochina@igsnrr.ac.cn)

All the data sources used in the material extensions are indicated in Sections S2 are openly available to researchers. China's customs data can be obtained through purchase or direct request from the Chinese customs. It also can be requested from the authors for reasonable purposes.

REFERENCE

1. Meng, B.; Yamano, N., Compilation of a regionally extended inter-country input–output table and its application to global value chain analyses. *Journal of Economic Structures* **2017,** *6*, (1), 23.
2. Eurostat *Economy-wide material flow accounts (EW-MFA): Compilation guide 2013*; Eurostat: Luxembourg, 2013.
3. International Resource Panel *Global Material Flows Database*; United Nations Environment Programme: Paris, 2017.
4. International Resource Panel *Technical annex for Global Material Flows Database*; United Nations Environment Programme: Paris, 2018.
5. China Agriculture Press *China Agriculture Yearbook*; China Agriculture Press: Beijing, 2011.
6. National Bureau of Statistics of China *China Rural Statistical Yearbook*; China Statistics Press: Beijing, 2011.
7. National Bureau of Statistics of China *China Industry Economy Statistical Yearbook*; China Statistics Press: Beijing, 2011.
8. Jiang, M.; Behrens, P.; Wang, T.; Tang, Z.; Yu, Y.; Chen, D.; Liu, L.; Ren, Z.; Zhou, W.; Zhu, S.; He, C.; Tukker, A.; Zhu, B., Provincial and sector-level material footprints in China. *Proc. Natl. Acad. Sci. U. S. A.* **2019,** *116*, (52), 26484-26490.
9. China Nonferrous Metals Industry Association *China Nonferrous Metals Industry Yearbook*; China Nonferrous Metals Industry Association: Beijing, 2011.
10. Institute for Circular Economy of Tsinghua University *Progress report of National science and technology support project on Researches and demonstrations of key technologies on regional circular economy development of China*; Institute for Circular Economy of Tsinghua University: Beijing, 2016.
11. National Bureau of Statistics of China *Training manual for resource productivity pilot survey*; National Bureau of Statistics of China: Beijing, 2012.
12. Editorial Office of China Mining Yearbook *China Mining Yearbook*; Seismological press: Beijing, 2011.
13. China Cement Association *China Cement Almanac*; China Building Materials Press: Beijing, 2011.
14. Wang, H.; Tian, X.; Tanikawa, H.; Chang, M.; Hashimoto, S.; Moriguchi, Y.; Lu, Z., Exploring China's materialization process with economic transition: analysis of raw material consumption and its socioeconomic drivers. *Environ. Sci. Technol.* **2014,** *48*, (9), 5025-5032.
15. National Bureau of Statistics of China *China Energy Statistics Yearbook*; National Statistics Press: Beijing, 2011.
16. Stadler, K.; Wood, R.; Bulavskaya, T.; Södersten, C. J.; Simas, M.; Schmidt, S.; Usubiaga, A.; Acosta‐Fernández, J.; Kuenen, J.; Bruckner, M., EXIOBASE 3: Developing a time series of detailed environmentally extended multi‐regional input‐output tables. *J. Ind. Ecol.* **2018,** *22*, (3), 502-515.
17. Division of Development Strategy and Regional Economy of Development Research Center of China's State Council *Social and economic analysis of mainland China*; Development Research Center of China's State Council: Beijing, 2003.
18. Wiebe, K. S.; Lenzen, M., To RAS or not to RAS? What is the difference in outcomes in multi-regional input–output models? *Econ. Syst. Res.* **2016,** *28*, (3), 383-402.
19. Liu, W.; Tang, Z.; Chen, J.; Yang, B. *China's interregional input-output tables between 30 provinces in 2010*; China Statistics Press: Beijing, 2014.

List of Table

List of Figure