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Accounting for the carbon footprints and embodied primary resource using multi-region input-output analysis: Iron and steel sector for the case of Japan

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Motivations

- International trade greatly contributed to the national economic growth but at the same time caused many environmental problems such as resource extraction and depletion, CO2 emissions and ecological degradation, etc.
- Because of trade, manufactured goods can be shifted from one country to another; however, the environmental burdens associated with the production of the goods are left to the country of origin.
- Global supply chain and hidden upstream burdens
- Limitations of domestic policies to address the overall resource efficiency of the supply chain and the problem of environmental burden shifting from developed to developing countries via trade.

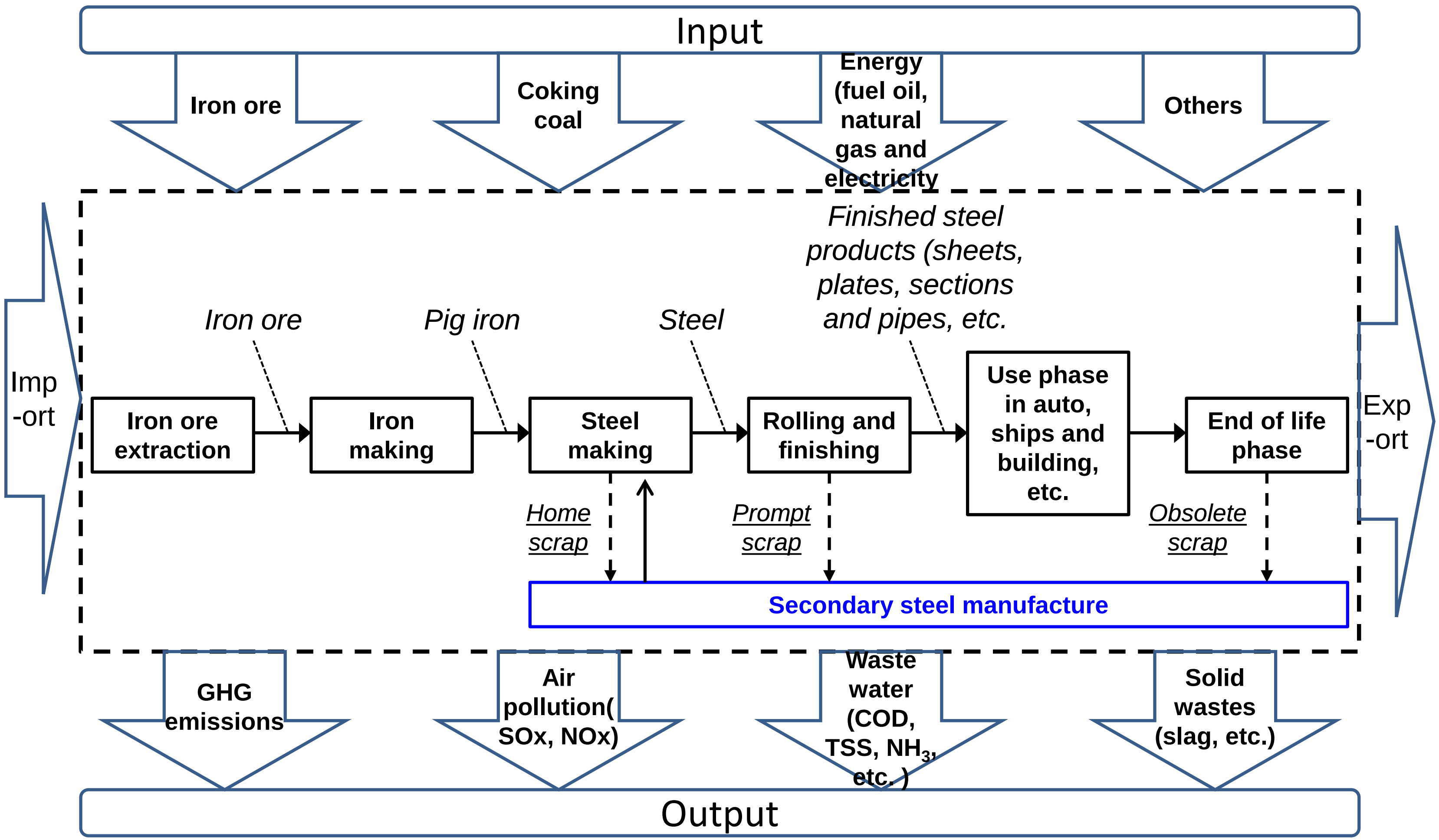
Objectives

- To account for the carbon footprints and primary resource use that are embodied in the finished products;
- To assess the use of primary vs. recycled material in the finished products;
- To assess the international trade patterns for both primary resource, intermediate goods and finished goods.

Iron and Steel Sector

- A non-renewable but recyclable material facing the challenge of scarcity and various competing uses;
- Economic growth and increasing consumption in emerging countries, in particular cars, buildings and infrastructure;
- Major energy consumer and CO_2 emitter;
- Post-consumption and waste management;
- Considerable amount of international trade of both virgin and secondary resources, and intermediate and finished products.

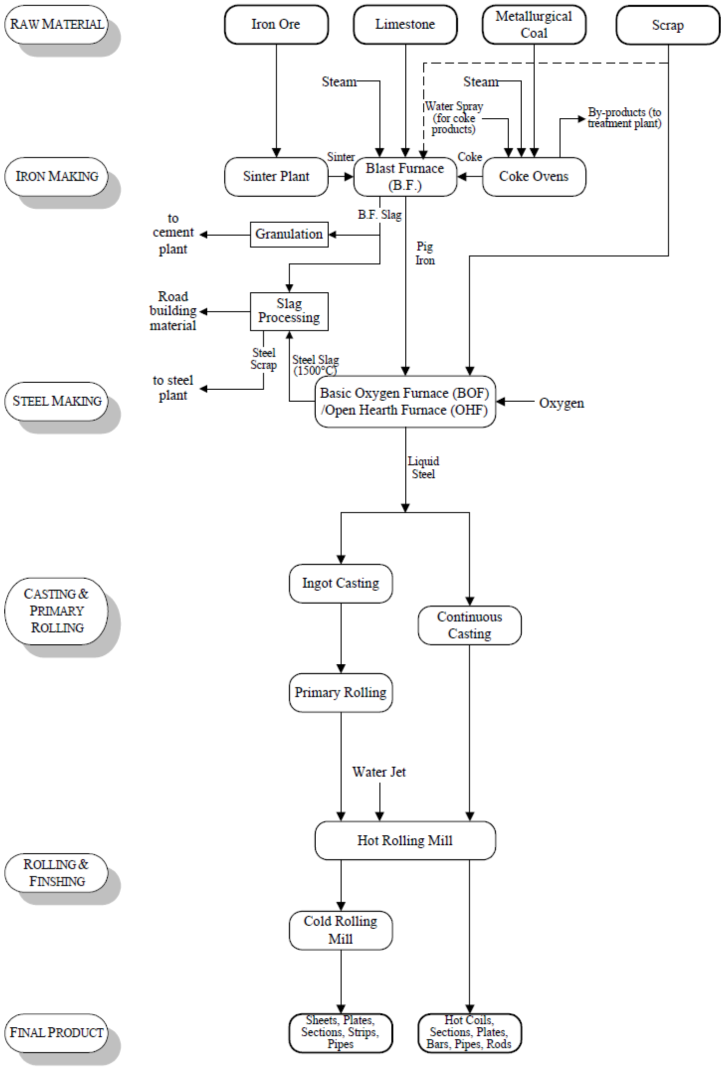
Simplified Iron Cycle



Process I: Integrated iron and steel mills

Simplified flow diagram of integrated iron and steel mills

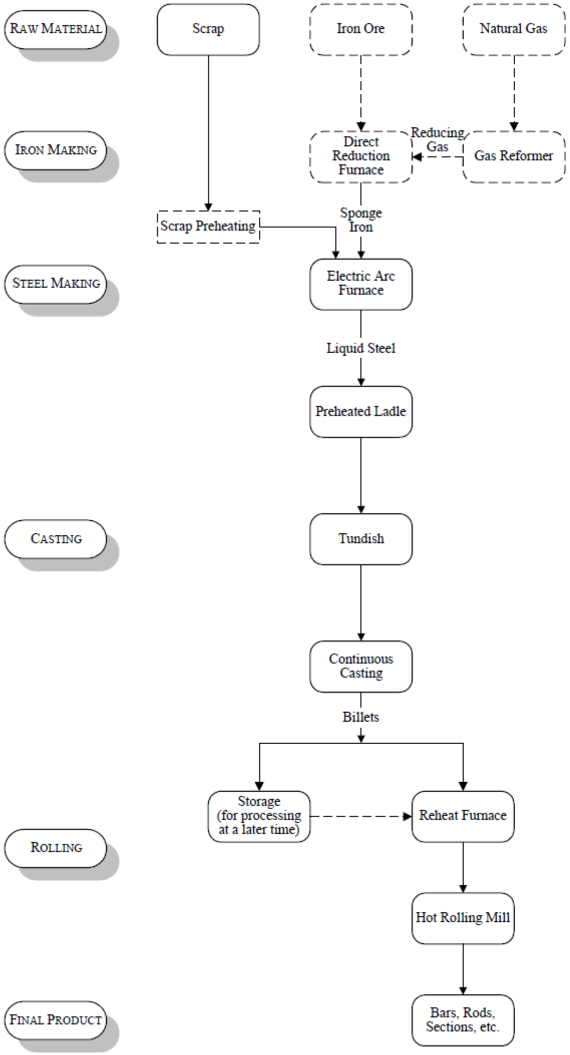
- Blast furnace for producing pig iron
- Major material inputs: iron ore and limestone;
- Major energy inputs: coking coal, oil and electricity



Process II: Mini steel mills

Simplified flow diagram of mini steel mills

- Electric arc furnace for steel making
- Major material inputs: steel scraps
- Major energy inputs: natural gas and electricity



Methodology and Data

Methodology

- Constructed a global MRIO model based on the GTAP 7 database
- 11 regions (JPN, CHN, AUS, KOR, USA, IND, BRA, EU25, I_M, EOG, ROW)
- Including subsectors to reflect different stages of the iron and steel supply chain by disaggregating the GTAP sectors into more details:

  mining → iron ore extraction and other mining;

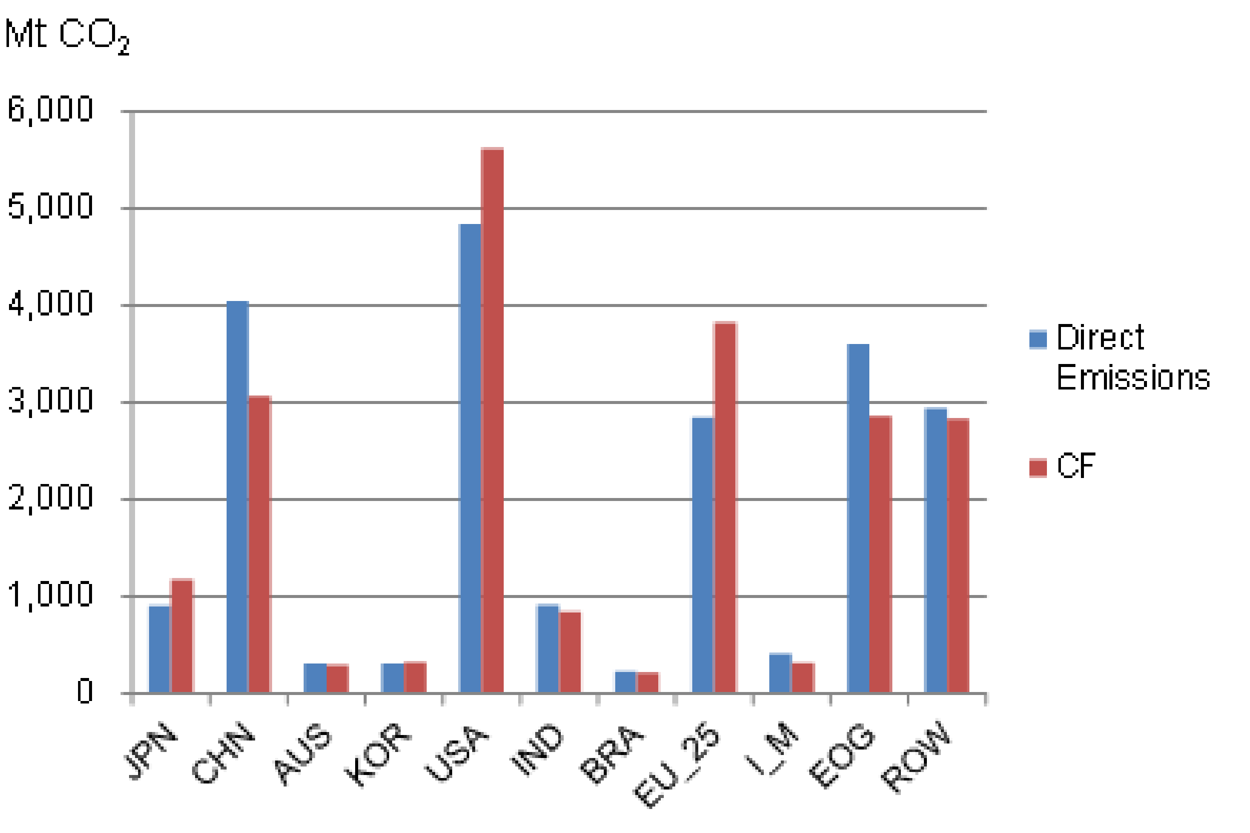
  iron and steel → pig iron, steel making by BF, and steel making by EAF;

  manufacturing → other manufacturing, steel recycling, and other recycling
- Categorize 11 regions into two groups; Countries using more BF technology and primary iron, and countries using more EAF technology and scraps.

Data Sources

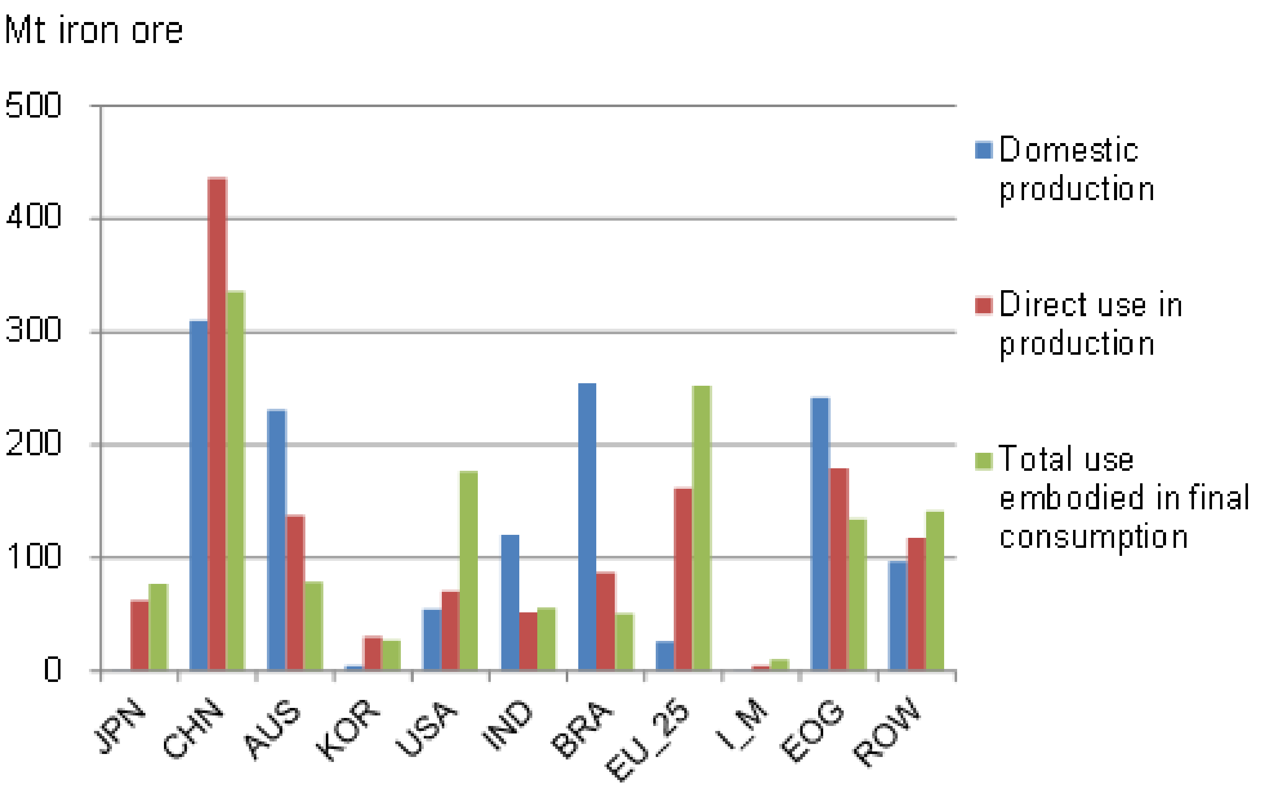
- To disaggregate the intermediate inputs, final demand, bilateral trade, and output, we used more detailed national I-O tables of Japan (for BF countries) and the US (for EAF countries), World Steel Statistical Yearbook, Global Trade Database compiled by IDE-JETRO, and the COMTRADE database.

Direct emissions and carbon footprints of final consumption



- CF = DE (AUS, KOR, BRA)
- CF < DE (CHN, IND, I_M, EOG, ROW)
- CF > DE (JPN, USA, EU25)

Domestic iron extraction, direct iron use in iron and steel making and indirect iron use embodied in finished goods



- Major iron ore producing countries: CHN, BRA, AUS, IND
- Major iron and steel producing countries: CHN, EU25, AUS, BRA
- Major consuming countries: CHN, EU25, USA, AUS, JPN

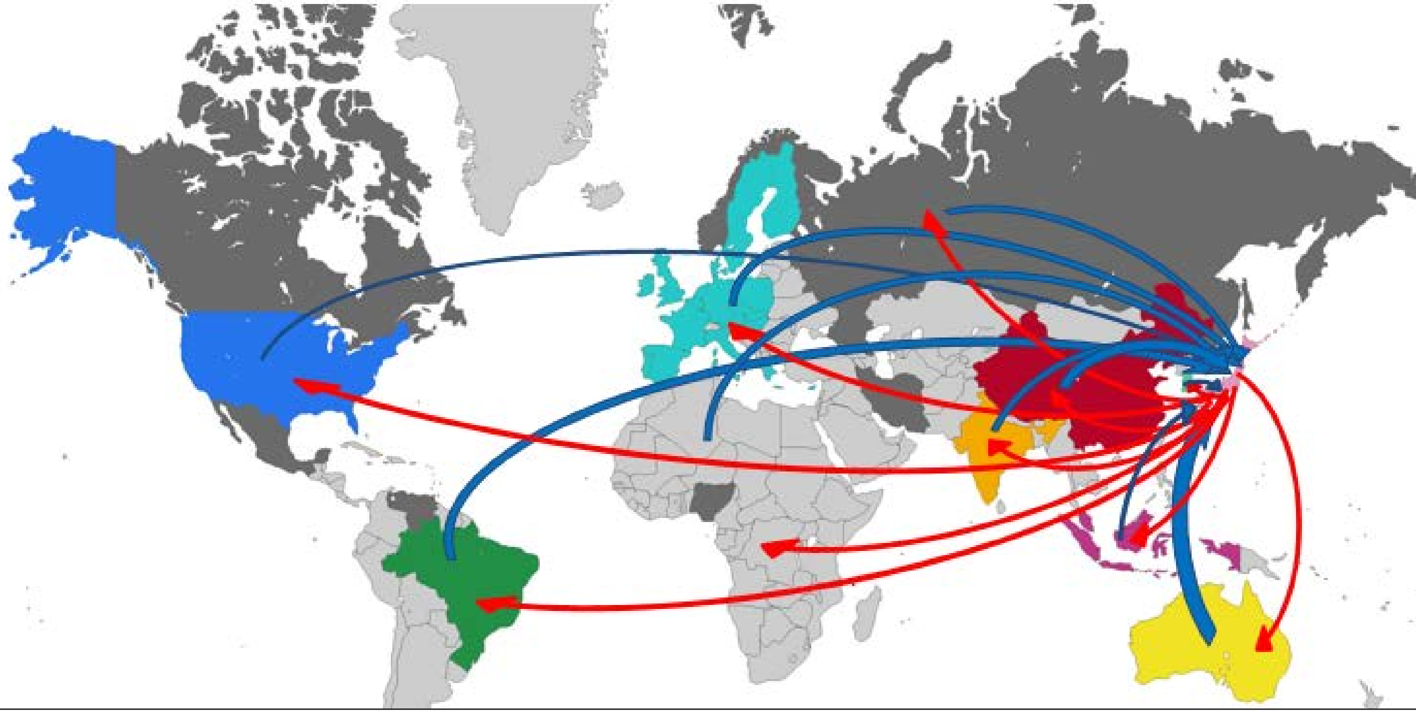
Intensity of direct emissions

Sector code	JPN	CHN	AUS	KOR	USA	IND	BRA	EU_25	I_M	EOG	ROW
iro	0.200	0.376	0.223	0.118	0.011	0.557	0.491	0.110	**0.577**	0.901	0.246
pio	0.603	2.332	0.902	0.710	1.207	3.006	1.706	0.644	**3.250**	3.362	2.895
csb	0.007	0.025	0.010	0.008	0.013	0.033	0.019	0.007	0.035	**0.037**	0.032
cse	0.045	0.173	0.067	0.053	0.090	0.223	0.127	0.048	0.242	**0.250**	0.215
mvh	0	**0.123**	0	0.021	0.026	0.006	0.001	0.010	0.035	0.010	0.024
otn	0.005	**0.102**	0	0.091	0.028	0.005	0.002	0.020	0.082	0.021	0.038
ele	0.012	0.023	0.002	0.004	0.015	0.025	0.005	0.006	0.027	**0.107**	0.028
ome	0.008	**0.106**	0.007	0.009	0.022	0.043	0.009	0.014	0.071	0.078	0.055
cns	0.018	0.065	0.024	0.017	0.011	0.010	0.001	0.015	0.079	**0.072**	0.045

Intensity of embodied emissions

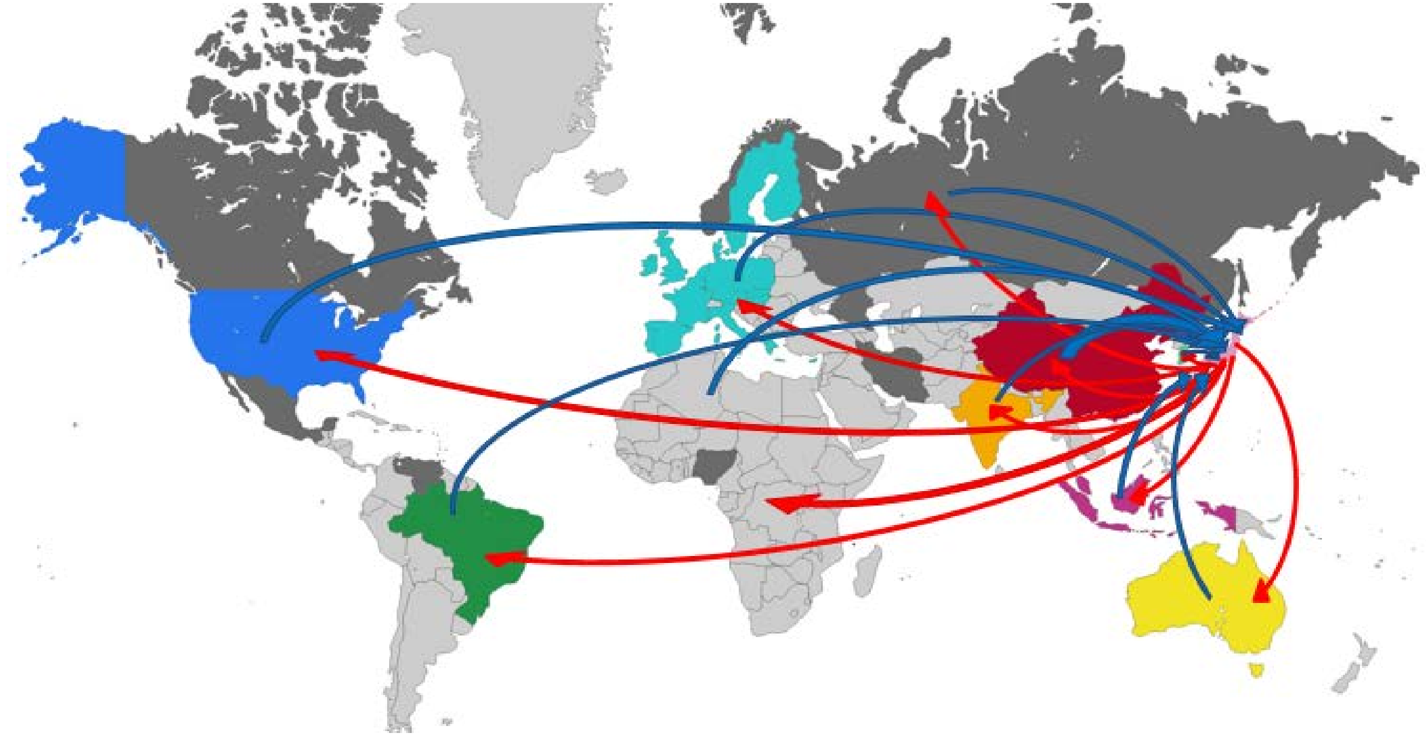
Sector code	JPN	CHN	AUS	KOR	USA	IND	BRA	EU_25	I_M	EOG	ROW
iro	0.612	2.172	0.959	**4.349**	0.379	0.004	0.015	1.146	1.016	2.395	1.199
pio	0.120	2.517	1.299	0.064	0.403	5.357	0.038	0.799	4.019	**6.500**	5.866
csb	0.065	1.560	0.725	0.035	0.192	2.640	0.021	0.422	2.173	**2.851**	1.922
cse	0.070	1.693	1.112	0.018	0.147	2.748	0.042	0.496	0.898	2.672	**2.862**
mvh	0.191	**1.763**	0.734	0.369	0.824	1.508	0.486	0.342	0.874	0.501	0.894
otn	0.349	**1.611**	1.487	0.251	0.427	1.460	0.254	0.414	1.058	0.820	1.302
ele	0.426	0.533	2.888	0.343	0.932	**2.173**	0.624	0.552	0.330	1.008	0.542
ome	0.356	1.615	1.182	0.431	0.623	**1.947**	0.635	0.364	0.849	1.152	1.024
cns	0.270	**2.393**	0.426	0.581	0.055	1.362	0.331	0.365	1.312	0.984	0.740

Embodied iron ores and trade flows for Japan (Mt)



National Japan	596 ton	Korea to Japan	0.1 Mt	Brazil to Japan	16.5 Mt	EOG to Japan	7.7Mt
		Japan to Korea	8 ton	Japan to Brazil	0.5 ton	Japan to EOG	6 ton
China to Japan	11.8 Mt	USA to Japan	1.1 Mt	EU_25 to Japan	0.4 Mt	ROW to Japan	5.6 Mt
Japan to China	0 ton	Japan to USA	23 ton	Japan to EU_25	22 ton	Japan to ROW	24 ton
Australia to Japan	26.7 Mt	India to Japan	7.1 Mt	I_M to Japan	0.1 Mt		
Japan to Australia	2 ton	Japan to India	2 ton	Japan to IMN	3 ton		

Carbon footprints and trade flow for Japan (Mt CO2)



National Japan	977.49	Korea to Japan	7.22	Brazil to Japan	0.63	EOG to Japan	6.32
		Japan to Korea	3.62	Japan to Brazil	0.57	Japan to EOG	4.44
China to Japan	79.44	USA to Japan	25.21	EU_25 to Japan	14.2	ROW to Japan	35.12
Japan to China	7.13	Japan to USA	25.27	Japan to EU_25	17.52	Japan to ROW	23.73
Australia to Japan	3.1	India to Japan	1.89	IMN to Japan	7.7		
Japan to Australia	2.37	Japan to India	0.61	Japan to IMN	2.39		

Carbon footprints and international trade for Japan's sectors

	Total	IRO	PIO	BF	EAF	MVH	OTN	ELE	OME	CNS
JPN	997.49 (84.65%)	1157.95 (65.54%)	6648.66 (19.84%)	3818.61 (20.94%)	2006.36 (20.46%)	23.74 (80.56%)	2.9 (47.55%)	48.98 (62.10%)	41.78 (57.45%)	148.45 (97.91%)
CHN	79.44 (6.74%)	41.79 (2.37%)	12582.08 (37.55%)	6236.35 (34.20%)	1687.90 (17.21%)	1.69 (5.73%)	1.10 (18.15%)	14.11 (17.90%)	17.32 (23.82%)	0.46 (0.30%)
AUS	3.10 (0.26%)	131.29 (7.43%)	131.19 (0.39%)	98.57 (0.54%)	22.79 (0.23%)	0.03 (0.09%)	3.54* (0.06%)	0.01 (0.01%)	0.06 (0.08%)	0.02 (0.02%)
KOR	7.22 (0.61%)	0.22 (0.01%)	2934.81 (8.76%)	2038.55 (11.18%)	2374.20 (24.21%)	0.18 (0.60%)	0.01 (0.21%)	1.78 (2.26%)	1.05 (1.44%)	0.03 (0.02%)
USA	25.21 (2.14%)	33.65 (1.90%)	380.69 (1.14%)	185.60 (1.02%)	247.77 (2.53%)	0.80 (2.73%)	1.55 (25.52%)	2.43 (3.08%)	3.62 (4.98%)	0.30 (0.20%)
IND	1.89 (0.16%)	38.30 (2.17%)	801.84 (2.39%)	185.60 (1.62%)	308.42 (3.14%)	0.02 (0.08%)	2.04* (0.03%)	5751.63* (0.01%)	0.17 (0.24%)	0.06 (0.04%)
BRA	0.63 (0.05%)	21.12 (1.20%)	713.36 (2.13%)	234.87 (1.29%)	68.69 (0.70%)	0.01 (0.03%)	1.13* (0.02%)	2202.97* (0.00%)	0.02 (0.02%)	0 (0%)
EU_25	14.20 (1.21%)	2.89 (0.16%)	484.58 (1.45%)	257.67 (1.41%)	144.31 (1.47%)	1.94 (6.59%)	0.16 (2.56%)	0.42 (0.53%)	2.41 (3.31%)	0.96 (0.63%)
I_M	7.70 (0.65%)	78.70 (4.45%)	372.01 (1.11%)	162.02 (0.89%)	201.92 (2.06%)	0.13 (0.44%)	0.04 (0.60%)	2.98 (3.77%)	1.07 (1.48%)	0.13 (0.09%)
EOG	6.32 (0.54%)	165.16 (9.35%)	1034.56 (3.09%)	432.492 (2.37%)	607.76 (6.20%)	0.10 (0.34%)	0.09 (1.49%)	0.28 (0.35%)	0.46 (0.63%)	0.60 (0.40%)
ROW	35.12 (2.98%)	95.79 (5.42%)	7420.61 (22.15%)	4474.658 (24.54%)	2137.53 (21.79%)	0.83 (2.82%)	0.23 (3.80%)	7.88 (9.99%)	4.76 (6.55%)	0.60 (0.40%)

Conclusions

- Downstream sectors of the iron and steel supply chain, including motor vehicles, electronic equipment, machinery and construction, have large amount of hidden flows.
- Most manufacturing sectors in Japan are among the most efficient sectors in terms of emissions intensity. However when using carbon footprint as the indicator for efficiency assessment, the results will be different due to the fact that some of the upstream productions are located in other countries which have less efficiencies.
- Japan's iron and steel supply chain is heavily dependent on the upstream productions in AUS, BRA, CHN, IND and EOG countries
- To address the hidden flows and associated environmental burdens in the upstream productions, increase the resource efficiency of the whole supply chain and reduce global emissions, Japan needs to cooperate with relevant countries and make policies such as payment for ecosystem services and imposing resource use tax, etc.

Future research

- For the elaboration of the MRIO model and improvement in data, we will conduct firm-level surveys of iron mining in Australia and I&S related sectors in China.
- For policy assessment (e.g. resource tax), we are building the multi-region CGE model based on SAM. The CGE results on the changes in outputs, final demand and bilateral trade due to the policy implementation will be used to update the MRIO model and to re-calculate the CFs and embodied resource to assess the impacts of policies on global emissions, resource use efficiency and total resource use.
- The methodology developed in particular the linkage of the embodied emissions and resource use analysis based on MRIO and CGE model for policy analysis can be applied to other resource assessment.

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Thank you!