Accounting for the carbon footprints and embodied primary resources using multi-region input-output analysis

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1. Introduction

From 1971 to 2010, world trade grew fast by 10% per year on average (World Trade Organization, 2011). The rapid growth of international trade contributed not only to national economic growth but also to the increasing of environmental pressures, such as raw material extraction and depletion, carbon emissions, water resource deterioration, landscape change and soil degradation. Most of the environmental pressures do not constitute as part of the traded products but remain as hidden burdens to the producing countries. These are usually called as upstream burdens.

The main purpose of this work is to address the cross-border upstream burdens in the supply chain of iron and steel products focusing on iron ore extraction, steel scraps recycling and carbon emissions. In this research, materials and primary resources used in upstream productions of traded products are called materials embodied in trade and carbon emissions generated from upstream productions are called emissions embodied in trade, or carbon footprint (CF). Accounting for indirect materials and emissions embodied in trade is important to national decision makers who concern about the life-cycle impacts of domestic production and consumption.

First, when policies aim solely at the improvement in domestic resource efficiency, the global impacts, such as climate change and resource depletion due to the outsourcing of raw materials and components to other countries, cannot be addressed properly. Japan can be considered as one of the most efficient countries in resource and energy use in the world. However, taking indirect material use and emissions into account, Japan's efficiency profiles can be different. For example, from 1980 until 2005, Japan had continuously the highest net amount of materials embodied in imports, most of which were from developing countries that had much lower resource efficiencies (Dittrich, 2010). To understand the material flows and sources of emissions along the supply chain is therefore important to make policies which address not only nation-wide material use efficiency and emissions but also global resource efficiency and emissions.

Second, due to the existence of hidden upstream burdens, the true costs of production are not fully reflected in the transaction costs. This is so-called environmental burden shifting via trade. A worse case is that environmental burdens will continuously shift from developed countries to developing countries, which lack

both technologies and financial capacity to prevent and remedy the ecological damages. Analysis of material flows and sources of emissions of the global supply chain is therefore necessary to help assess trade patterns and trace ecological impacts.

This work focused on iron metal because it is one of the fundamental materials supporting modern economic growth. Iron and steel production is one of the most energy-intensive sectors and dependent on iron metal which is a non-renewable resource. As both an importing and exporting country, Japan plays an important role in global iron and steel production and consumption. Report from the World Steel Recycling (Bureau of International Recycling, 2011) shows that there has been significantly increasing of scraps used in steelmaking process, which can help reduce both virgin material use and carbon emissions. Focusing on both iron metals and steel scraps used in Japan's iron and steel making, this study includes international trade among eleven regions, which include two major iron ore producing countries (Australia and Brazil), six steel producing countries (China, India, Japan, Korea, EU-25 and the US), two major oil and gas producing country groups (Indonesia & Malaysia, and other major oil and gas exporting countries (EOG)) and the rest of the world (ROW) (see Appendix A1 for region classification).

We constructed a global multi-region input-output (MRIO) model based on the GTAP 7 Database (Center for Global Trade Analysis) and calculated materials and emissions embodied in major downstream uses of iron and steel products. We compared the total resource efficiency and emissions of sectors across countries and assessed the international trade patterns of iron ores, steel scraps and iron and steel products in terms of material flows and carbon emissions.

2. Methodology

The GTAP 7 Database provides national input-output (IO) tables and bilateral trade data for 57 sectors of 113 regions in the world. Based on the same assumption on the trade tables as of the Chenery-Moses type of MRIO (Chenery, 1953; Moses, 1955; Miller and Blair, 1985), we constructed a global MRIO model and re-classified sectors into 57 (see Appendix A2). By using the global MRIO, both direct resource use and emissions and indirect resource use and emissions due to upstream productions can be calculated and the source countries of iron ore extraction and emissions can be identified explicitly.

To capture the virgin vs. secondary material use in iron and steel making, we divided the iron and steel making sector into three subsectors, i.e. pig iron (sector code "pio"), steel making by blast furnace using iron ores as major inputs (code "csb") and the technology of electric arc furnace using steel scraps (code "cse"). For virgin material extraction, we separate iron ore (code "iro'") from the sector of other mining (code "omn"). To capture the impacts of steel scrap recycling, we singled out steel scraps recycling (code "ssr"), other scraps recycling (code "osr") from other manufacturing (code "omf"). In addition, to have less detail on cereal grains and animal products, we aggregate three cereal grains into one sector ("grc") and four animal products into one sector ("lst"). Other sectors are kept the same as those defined in the GTAP 7 Database.

Before disaggregating relevant sectors, we categorized eleven-regions into two groups: one is mainly using blast furnace technology and the other is mainly using electric arcfurnace technology for steel production. The classification is based on the ratio of crude steel production by blast furnace and by electric arc furnace using the data from the World Steel Statistical Yearbook in year 2004 (World Steel Association, 2011). In other words, we classify countries with higher ratio of crude steel production by blast furnace than the ratio

by electric arc furnace as blast furnace steel producing countries and those with higher ratio of crude steel production by electric arc furnace than the ratio by blast furnace as electric arc furnace steel producing countries. Japan, Australia, Brazil, China, EU-25 and the ROW are grouped as blast furnace steel producing countries. The US, India, South Korea, Indonesia & Malaysia (I_M) and other major oil and gas exporting countries (EOG) are grouped as electric arc furnace steel producing countries. Data sources and procedures to disaggregate relevant sectors are as follows.

i) Disaggregation of domestic intermediate inputs, final demand and outputs

To disaggregate domestic intermediate inputs, final demand and outputs of the original sectors defined in the GTAP Database, we used national IO tables of four countries (Japan, China, Australia and the US), World Steel Statistical Yearbook and Global Trade Atlas Database compiled by the IDE JETRO (Institute of Developing Economies, Japan External Trade Organization, 2012) (for details see Appendix A3). Firstly, we mapped sectors defined in the national IO tables of four countries into GTAP 7 Database's sector classification (see Appendix A1). Secondly, we calculated the ratio of each disaggregated sector based on national IO values or output values from World Steel Statistical Yearbook. In detail, the ratio for each disaggregated sector is the output value of each disaggregated sector divided by the total output value of the corresponding aggregate sector (e.g. the ratio of iron ore is the output value of iron ore divided by the total output value of mining in the national IO table). Thirdly, we applied the ratios to separate the aggregate sector defined by the GTAP 7 Database by multiplying the value of the aggregate sector by the ratio of each disaggregated sector (e.g. the value of iron ore sector is the value of other mining in the GTAP 7 Database multiplied by the ratio of iron ore calculated based on the national IO table).

To disaggregate steel recycling and other recycling in Japan, we used Japan Waste IO Table 2000 (Nakamura and Kondo, 2010). Since Japan and the US have the most disaggregated sectors in their national IO tables, we used Japan's IO table as the reference for blast furnace steel producing countries and the US IO table as the reference for electric arc furnace steel producing countries. All data used to calculate the ratio in this study are based on monetary value. Since data from World Steel Statistical Yearbook is provided in physical units, we multiplied the physical unit-based data with export unit prices to convert physical values into monetary values. We calculated export unit prices by dividing the total export value by the total export quantity for each disaggregated sector. Export data used here is based on the Global Trade Atlas Database compiled by the IDE JETRO and the UN COMTRADE (United Nations Commodity Trade Statistics Database, 2012).

ii) Bilateral trade

We used trade data provided by the UN COMTRADE and the Global Trade Atlas Database to break down the bilateral trade matrix for sectors of iron ore, other mining, pig iron, other manufacturing, steel recycling and other recycling. Since trade data for crude steel produced either by blast furnace or by electric arc furnace are not available, we used the ratios of crude steel produced by blast furnace and by electric arc furnace, provided by the World Steel Statistical Yearbook, to separate crude steel trade data into trade data for crude steel produced by blast furnace and by electric arc furnace, respectively. We followed the same procedure used to break down domestic intermediate inputs, final demand and outputs of the aggregate sectors.

3. Results

3.1 Primary resource use and carbon emissions

To address the hidden flows in the upstream productions of the supply chain of iron and steel products, we use the indicator of carbon footprints and embodied iron ores. Fig.A1 shows national direct emissions from producer perspective and carbon footprints of final demand from consumer perspective. Similarly, Fig.A2 shows the comparison of direct iron ore use and total iron ores embodied in the final consumption of all sectors in each economy.

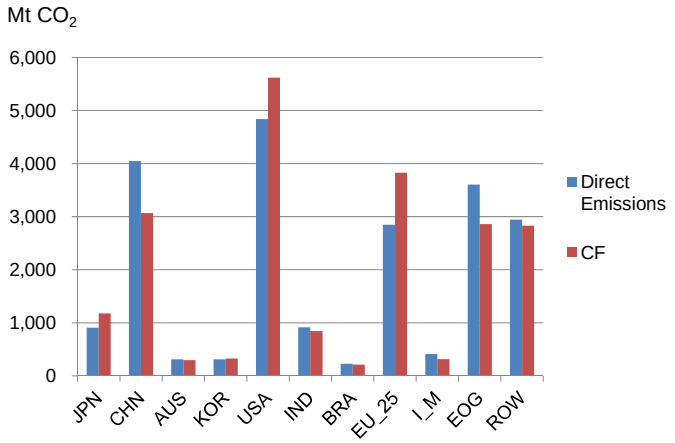

Figure A1 Direct emissions and carbon footprints of final consumption

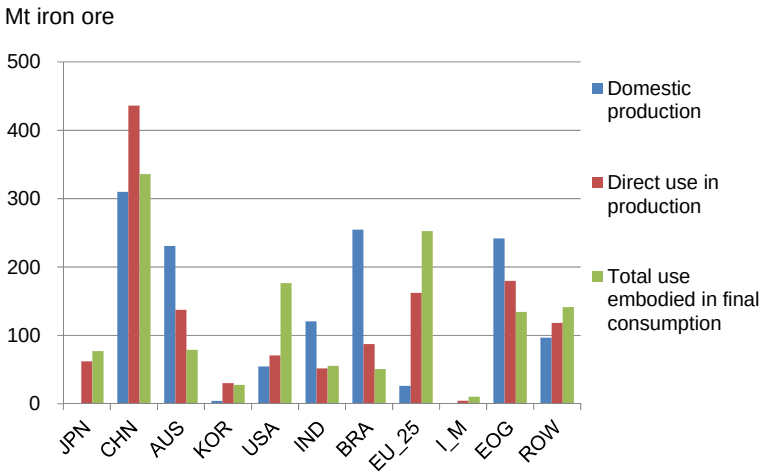

Figure A2 Domestic production, direct use in production and embodied iron ores in final consumption

When comparing national direct emissions with carbon footprints, there are three patterns: i) direct emissions and CFs are about the same (Australia, Korea and Brazil); ii) direct emissions are greater than CFs (China, India, Indonesia & Malaysia, EOG, and ROW); and iii) direct emissions are less than CFs (Japan, the US and EU-25). In particular, the US and EU-25 have much larger CFs than the direct emissions from production, and China and EOG countries have much larger direct emissions than the CFs.

Comparing iron ore production and consumption, there are two groups of countries. Australia, India, Brazil and EOG countries are among major iron ore producing countries in the world and have greater production than consumption, while other countries have greater consumption than production, in particular Japan, China and EU-25. China is distinguished from Japan and EU-25 in that China is both the largest producing country and the largest consuming country. In terms of direct use of iron ores in production and iron ores embodied in final consumption, we found Japan, the US, EU-25 and the ROW have larger amount of iron ores embodied in their final consumption than the direct use in production, while China, Australia, Brazil and EOG countries have more direct use in production than the amount of iron ores embodied in final consumption. Korea, India and Indonesia & Malaysia have about the same amount of the direct use of iron ores in production and embodied iron ores in consumption.

Comparison of direct emissions and CFs for selected sectors is presented in Figs. A3 - A11. Generally speaking, upstream productions in the supply chain of iron and steel products, such as iron ore extraction (iro) and pig iron production (pio), have more direct emissions than their CFs, while major downstream productions have more CFs than the direct emissions from production, such as motor vehicle manufacturing (mvh), other transportation equipment (otn), electronic equipment (ele), other machinery and equipment (ome) and construction (cns). Crude steel from blast furnace (csb) and crude steel from electric arc furnace (cse) have mixed results.

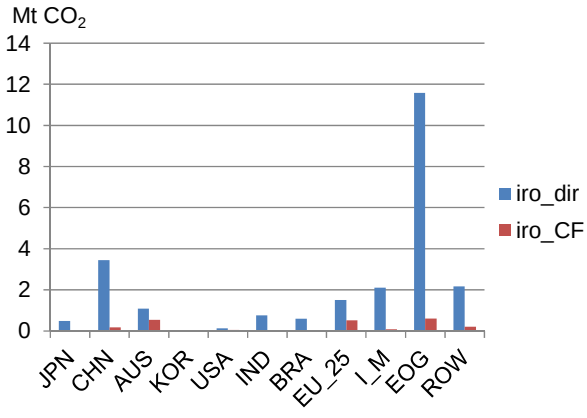

Figure A3 Direct emissions and CFs of iron ore sector

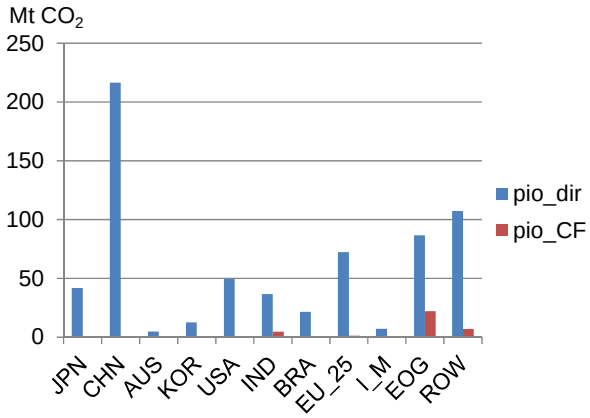

Figure A4 Direct emissions and CFs of pig iron sector

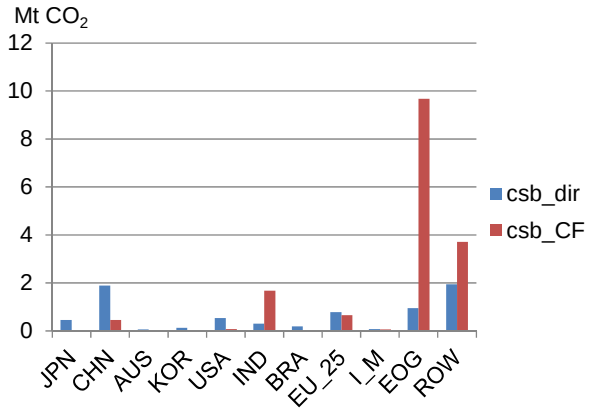

Figure A5 Direct emissions and CFs of blast furnace crude steel sector

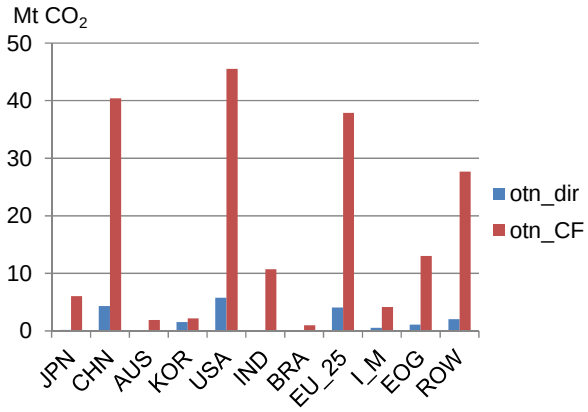

Figure A8 Direct emissions and CFs of other transport equipment sector

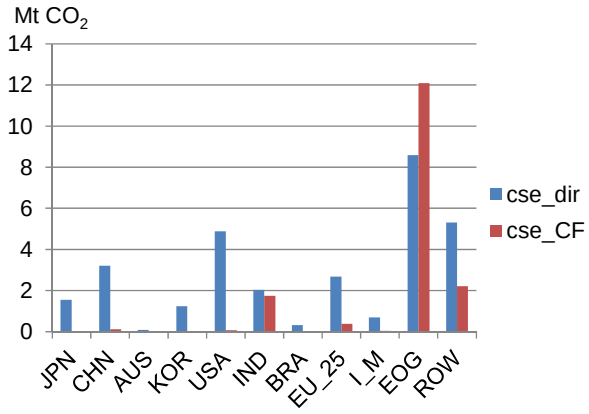

Figure A6 Direct emissions and CFs of electric arc furnace crude steel sector

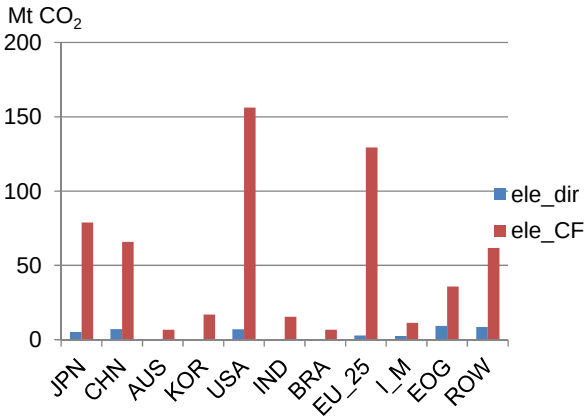

Figure A9 Direct emissions and CFs of electronic equipment sector

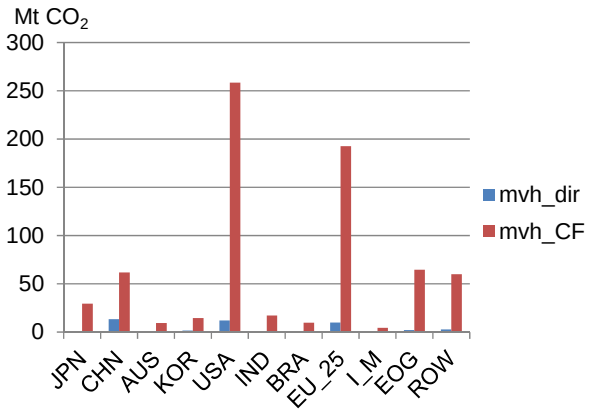

Figure A7 Direct emissions and CFs of motor vehicle sector

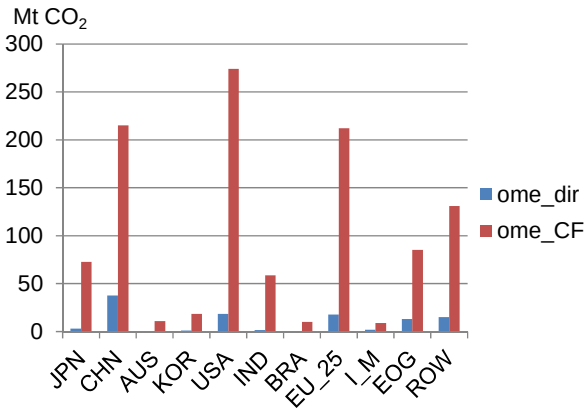

Figure A10 Direct emissions and CFs of other machinery and equipment sector

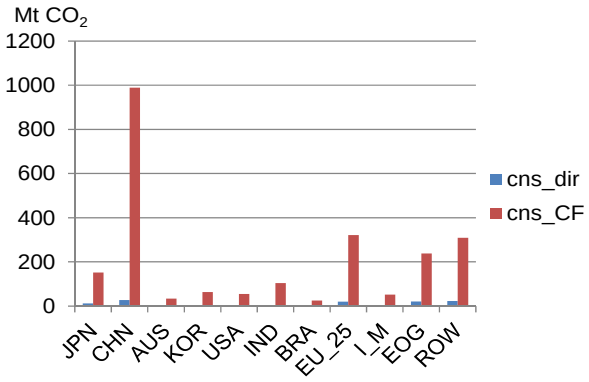

Figure A11 Direct emissions and CFs of construction sector

3.2 Resource efficiency and carbon intensity

Tables A1 and A2 present the carbon emissions from per unit production (i.e. direct emissions/sectoral output) and embodied emissions per unit final consumption (i.e. embodied emissions/sectoral final consumption) for selected sectors.

For the carbon intensity of direct emissions from production, Japan has the least intensity for the sectors of pio, csb, cse and mvh. Except for sector iro, the carbon intensity of Japanese manufacturing sectors is relatively low among eleven regions. Australia has the least carbon intensity for the sectors of mvh, otn, ele and ome, while the US and Brazil has the least carbon intensity for sector iro and sector cns, respectively. On the other hand, China (mvh, otn and ome), Indonesia & Malaysia (iro and pio), and EOG countries (csb, cse, ele and cns) have the highest carbon intensity.

Table A1 Carbon emissions from per unit production (kg CO_2/US$_2004 value)

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

For the embodied carbon intensity of final consumption, different from the carbon intensity of direct emissions from production, Japan has the least intensity for the sectors of ome and cns. Korea (cse and otn), India (iro), Brazil (pio and csb), EU-25 (mvh) and Indonesia & Malaysia (ele) have the least embodied carbon intensity for respective sectors. On the other hand, China (mvh, otn and cns), Korea (iro), India (ele and ome), EOG countries (pio and csb) and ROW (cse) have the highest embodied carbon intensity for respective sectors.

Table A2 Embodied emissions per unit final consumption (kg CO_2/US$_2004 value)

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

3.3 International trade

In order to address the issue of emissions and primary resources embodied in the international trade of commodities, we traced the source countries for the CFs and iron ores embodied in final consumption. Tables A3 and A4 show the source countries of CFs and embodied iron ores of each country.

Table A3 Source countries of CFs (Mt)

	JPN	CHN	AUS	KOR	USA	IND	BRA	EU_25	I_M	EOG	ROW
JPN	997.49	7.13	2.37	3.62	25.27	0.61	0.57	17.52	2.39	4.44	23.73
	(84.65%)	(0.23%)	(0.79%)	(1.10%)	(0.45%)	(0.07%)	(0.27%)	(0.46%)	(0.76%)	(0.16%)	(0.84%)
CHN	79.44	3013.77	11.31	12.65	162.36	6.63	2.59	131.75	9.98	36.08	105.10
	(6.74%)	(98.26%)	(3.78%)	(3.84%)	(2.89%)	(0.78%)	(1.22%)	(3.44%)	(3.16%)	(1.26%)	(3.71%)
AUS	3.10	0.24	257.33	0.47	2.26	0.22	0.09	3.48	0.58	1.14	7.84
	(0.26%)	(0.01%)	(86.06%)	(0.14%)	(0.04%)	(0.03%)	(0.04%)	(0.09%)	(0.18%)	(0.04%)	(0.28%)
KOR	7.22	7.54	1.21	293.08	16.44	1.33	0.64	13.47	1.66	4.81	17.91
	(0.61%)	(0.25%)	(0.40%)	(89.00%)	(0.29%)	(0.16%)	(0.30%)	(0.35%)	(0.53%)	(0.17%)	(0.63%)
USA	25.21	5.18	6.40	6.34	5021.88	1.71	3.24	73.61	3.76	93.58	58.46
	(2.14%)	(0.17%)	(2.14%)	(1.93%)	(89.35%)	(0.20%)	(1.53%)	(1.92%)	(1.19%)	(3.27%)	(2.06%)
IND	1.89	0.36	0.66	0.25	15.40	823.90	0.22	18.20	1.01	3.62	21.14
	(0.16%)	(0.01%)	(0.22%)	(0.08%)	(0.27%)	(97.33%)	(0.10%)	(0.48%)	(0.32%)	(0.13%)	(0.75%)
BRA	0.63	0.21	0.19	0.15	4.97	0.33	194.90	6.77	0.13	3.41	7.54
	(0.05%)	(0.01%)	(0.06%)	(0.05%)	(0.09%)	(0.04%)	(91.88%)	(0.18%)	(0.04%)	(0.12%)	(0.27%)
EU_25	14.20	7.67	5.74	2.93	56.41	2.41	3.98	3314.10	3.36	36.82	92.38
	(1.21%)	(0.25%)	(1.92%)	(0.89%)	(1%)	(0.28%)	(1.88%)	(86.53%)	(1.06%)	(1.29%)	(3.26%)
I_M	7.70	2.98	2.38	1.09	18.15	2.27	0.31	17.85	279.79	3.51	22.96
	(0.65%)	(0.10%)	(0.79%)	(0.33%)	(0.32%)	(0.27%)	(0.15%)	(0.47%)	(88.48%)	(0.12%)	(0.81%)
EOG	6.32	1.99	1.67	1.77	205.34	1.29	1.66	62.66	1.47	2635.15	44.69
	(0.54%)	(0.06%)	(0.56%)	(0.54%)	(3.65%)	(0.15%)	(0.78%)	(1.64%)	(0.47%)	(92.12%)	(1.58%)
ROW	35.12	20.00	9.76	6.94	92.12	5.81	3.93	170.40	12.09	38.07	2429.72
	(2.98%)	(0.65%)	(3.27%)	(2.11%)	(1.64%)	(0.69%)	(1.85%)	(4.45%)	(3.82%)	(1.33%)	(85.81%)

Data on the diagonal of Table A3 indicates that most of developed economies including Japan, Australia, Korea, the US and EU-25 have lower percentage of CFs that are originated from domestic production, while most of developing countries, such as China, India, Brazil and EOG countries, have higher percentage of CFs that are generated from domestic production. As also indicated in Fig. A1, Japan, the US and EU-25 have much greater CFs than direct emissions while China and EOG countries have much higher direct emissions than CFs. In particular, except for the country itself (data on the diagonal), the major sources of the CFs of Japan, Australia and Korea is from China, the major source of the CFs of the US is from EOG countries, and the major sources of the CFs of EU-25 is from the ROW.

From sectoral point of view for Japan (see Appendix A4), for iron ore sector, 65.5% CFs are originated from Japanese domestic production, while EOG countries (9.3%) and Australia (7.3%) are major source countries for CFs of the iron ores consumption in Japan, due mainly to the imports of oil and gas from EOG countries and iron ores from Australia and corresponding upstream emissions in these countries. For pig iron sector, Japan has quite low percentage of CFs that is originated from domestic production (19.8%). Most of the CFs is originated from China, followed by the ROW. For China, it is mainly due to the large amount of pig iron imports of Japan from China and emissions from the production of pig iron in China. For the ROW, the reason why it contributes to a large amount of Japan's CFs is not very clear by current analysis. A sectoral Structural Path Analysis may help to explain the details about the supply

chain and international trade. For the sector of crude steel manufactured by blast furnace, CFs originated from Japan's domestic production is low (20.9%) and most of the CFs is originated from China and the ROW. For crude steel manufactured by electric arc furnace, CFs originated from Japan's domestic production is about 20.5% and most of the CFs is originated from Korea, the ROW and China.

For iron ores, from Table A4 we can see that Japan, Korea, the US, EU-25, Indonesia & Malaysia and the ROW have very low self-sufficiency in satisfying embodied iron ores in domestic consumption. Japan's embodied iron ores of domestic consumption is dependent on Australia (34.6%), Brazil (21.4%) and China (15.3%). Korea is similar to Japan and dependent on Australia (28.7%), Brazil (22.9%) and China (14.3%). The US is more dependent on EOG countries (23.2%), China (15.7%) and Brazil (15.2%). EU-25 is dependent on Brazil (26.8%) and EOG countries (22.7%). Indonesia and Malaysia are dependent on Australia (23.5%), Brazil (21.2%) and China (20.1%).

Table A4 Source countries of embodied iron ores (Mt)

	JPN	CHN	AUS	KOR	USA	IND	BRA	EU_25	I_M	EOG	ROW
JPN	596.33*	0	2.06*	7.8*	22.48*	1.61*	0.52*	21.64*	3.11*	5.5*	23.98*
	(0%)	(0%)	(0%)	(0%)	(0%)	(0%)	(0%)	(0%)	(0%)	(0%)	(0%)
CHN	11.81	205.46	2.03	3.94	27.72	2.47	0.64	28.82	2.11	6.44	18.56
	(15.31%)	(61.16%)	(2.58%)	(14.26%)	(15.70%)	(4.44%)	(1.25%)	(11.41%)	(20.15%)	(4.79%)	(13.11%)
AUS	26.70	30.05	72.25	7.92	18.44	10.76	0.63	31.23	2.46	6.70	23.81
	(34.62%)	(8.94%)	(91.70%)	(28.66%)	(10.44%)	(19.36%)	(1.24%)	(12.37%)	(23.52%)	(4.98%)	(16.82%)
KOR	0.12	0.24	0.02	3.33	0.22	0.03	0.01	0.21	0.03	0.08	0.23
	(0.15%)	(0.07%)	(0.02%)	(12.05%)	(0.12%)	(0.05%)	(0.02%)	(0.08%)	(0.26%)	(0.06%)	(0.16%)
USA	1.11	0.99	0.20	0.39	41.30	0.24	0.17	4.17	0.17	3.69	2.33
	(1.44%)	(0.29%)	(0.25%)	(1.41%)	(23.39%)	(0.44%)	(0.33%)	(1.65%)	(1.59%)	(2.74%)	(1.64%)
IND	7.08	37.28	0.84	1.79	10.53	29.47	0.27	17.03	1.19	2.69	12.44
	(9.18%)	(11.10%)	(1.06%)	(6.48%)	(5.96%)	(53.03%)	(0.53%)	(6.74%)	(11.39%)	(2.00%)	(8.79%)
BRA	16.52	43.85	1.50	6.34	26.90	3.90	47.27	67.80	2.22	10.13	28.58
	(21.42%)	(13.05%)	(1.90%)	(22.94%)	(15.24%)	(7.02%)	(92.80%)	(26.85%)	(21.21%)	(7.53%)	(20.19%)
EU_25	0.39	0.58	0.10	0.12	1.42	2.04	0.07	18.49	0.10	0.64	2.37
	(0.51%)	(0.17%)	(0.13%)	(0.42%)	(0.80%)	(3.67%)	(0.14%)	(7.32%)	(0.98%)	(0.48%)	(1.67%)
I_M	0.09	0.05	0.02	0.02	0.06	0.03	0	0.10	0.19	0.02	0.12
	(0.12%)	(0.01%)	(0.03%)	(0.06%)	(0.04%)	(0.05%)	(0.00%)	(0.04%)	(1.82%)	(0.01%)	(0.08%)
EOG	7.75	10.95	0.96	2.16	40.91	2.48	1.02	57.27	0.97	99.95	17.65
	(10.04%)	(3.26%)	(1.22%)	(7.82%)	(23.17%)	(4.47%)	(2.01%)	(22.67%)	(9.28%)	(74.28%)	(12.47%)
ROW	5.55	6.51	0.87	1.63	9.06	4.16	0.85	27.45	1.02	4.21	35.49
	(7.20%)	(1.94%)	(1.11%)	(5.90%)	(5.13%)	(7.48%)	(1.66%)	(10.87%)	(9.80%)	(3.13%)	(25.06%)

Note: * indicates the values are in tonnes.

4. Policy implications

By using MRIO analysis, this research helped to understand how much carbon emissions and primary resources (iron ores) as hidden flows are embodied in the final consumption. It also helped to trace the original countries where the emissions are generated and the iron ores are extracted and therefore helped to know where the impacts are located. Several policy implications are derived as follows:

i) Results indicate that downstream sectors in the iron and steel supply chain, including motor vehicles, other transportation equipment, electronic equipment, other machinery and

equipment and construction, have a large amount of hidden flows, i.e. embodied emissions and embodied iron ores.

ii) Most of Japan's manufacturing sectors are among most efficient in terms of carbon emissions generated directly from production and iron ores used directly in production, however, when look at CFs and iron ores embodied in consumption, the efficiencies are different due to some upstream productions are located in other countries which have less efficiency than in Japan.

iii) For the iron and steel supply chain, Japan is heavily dependent on the upstream productions in Australia, Brazil, China, India and EOG countries.

iv) Based on life-cycle way of thinking, addressing emissions generation and resource efficiency of domestic production cannot achieve the total reduction of emissions and resource use of the supply chain, which is provided through global cooperation and specialization. Policies to address the emissions and primary resources embodied in consumption are therefore important to reduce the total emissions and primary resource use in the supply chain.

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Appendix A1 Region classification

No	Country Classification	Description
1	JPN	Japan
2	CHN	China
3	AUS	Australia
4	KOR	Korea
5	USA	USA
6	IND	India
7	BRA	Brazil
8	EU25	EU_25: AUT, BEL, CYP, CZE, DNK, EST, FIN, FRA, DEU, GRC, HUN, IRL, ITA, LVA, LTU, LUX, MLT, NLD, POL, PRT, SVK, SVN, ESP, SWE, GBR
9	I_M	Indonesia and Malaysia
10	EOG	Major oil and gas exporting countries: XWS (middle east countries), RUS, IRN, NGA, XNF, MEX, VEN, CAN, NOR
11	ROW	Rest of the World in GTAP 7 Database

Appendix A2 Re-classification of sectors for the MRIO model

GTAP 7 Database			Classifications for the MRIO model		
No.	Sector Code	Sector Description	No.	Sector code	Sector description
1	Pdr	Paddy rice	1	grc	grains crops
2	Wht	Wheat			
3	Gro	Cereal grains nec			
4	v_f	Vegetables, fruit, nuts	2	v_f	Vegetables, fruit, nuts
5	Osd	Oil seeds	3	osd	Oil seeds
6	c_b	Sugar cane, sugar beet	4	c_b	Sugar cane, sugar beet
7	Pfb	Plant-based fibers	5	pfb	Plant-based fibers
8	Ocr	Crops nec	6	ocr	Crops nec
9	Ctl	Cattle,sheep,goats,horses	7	lst	Live stocks
10	Oap	Animal products nec			
11	Rmk	Raw milk			
12	Wol	Wool, silk-worm cocoons			
13	frs	Forestry	8	frs	Forestry
14	fsh	Fishing	9	fsh	Fishing
15	coa	Coal	10	coa	Coal
16	oil	Oil	11	oil	Oil
17	gas	Gas	12	gas	Gas
18	omn	Minerals nec	13	iro	iron ore mining
			14	omn	Other mining
19	cmt	Meat: cattle,sheep,goats,horse	15	cmt	Meat: cattle,sheep,goats,horse
20	omt	Meat products nec	16	omt	Meat products nec
21	vol	Vegetable oils and fats	17	vol	Vegetable oils and fats
22	mil	Dairy products	18	mil	Dairy products
23	pcr	Processed rice	19	pcr	Processed rice
24	sgr	Sugar	20	sgr	Sugar
25	ofd	Food products nec	21	ofd	Food products nec
26	b_t	Beverages and tobacco products	22	b_t	Beverages and tobacco products
27	tex	Textiles	23	tex	Textiles
28	wap	Wearing apparel	24	wap	Wearing apparel
29	lea	Leather products	25	lea	Leather products
30	lum	Wood products	26	lum	Wood products
31	ppp	Paper products, publishing	27	ppp	Paper products, publishing
32	p_c	Petroleum, coal products	28	p_c	Petroleum, coal products
33	crp	Chemical,rubber,plastic prods	29	crp	Chemical,rubber,plastic prods
34	nmm	Mineral products nec	30	nmm	Mineral products nec
35	i_s	Ferrous metals	31	pio	pig iron
			32	csb	Crude steel making by blast furnace
			33	cse	Crude steel making by electric arc furnace
36	nfm	Metals nec	34	nfm	Metals nec
37	fmp	Metal products	35	fmp	Metal products
38	mvh	Motor vehicles and parts	36	mvh	Motor vehicles and parts
39	otn	Transport equipment nec	37	otn	Transport equipment nec
40	ele	Electronic equipment	38	ele	Electronic equipment
41	ome	Machinery and equipment nec	39	ome	Machinery and equipment nec
42	omf	Manufactures nec	40	omf	Other manufacturing
			41	ssr	Steel scraps recycling
			42	osr	Other recycling
43	ely	Electricity	43	ely	Electricity
44	gdt	Gas manufacture, distribution	44	gdt	Gas manufacture, distribution
45	wtr	Water	45	wtr	Water
46	cns	Construction	46	cns	Construction
47	trd	Trade	47	trd	Trade
48	otp	Transport nec	48	otp	Transport nec
49	wtp	Sea transport	49	wtp	Sea transport
50	atp	Air transport	50	atp	Air transport
51	cmn	Communication	51	cmn	Communication
52	ofi	Financial services nec	52	ofi	Financial services nec
53	isr	Insurance	53	isr	Insurance
54	obs	Business services nec	54	obs	Business services nec
55	ros	Recreation and other services	55	ros	Recreation and other services
56	osg	PubAdmin/Defence/Health/Educat	56	osg	PubAdmin/Defence/Health/Educat
57	dwe	Dwellings	57	dwe	Dwellings

Appendix A3 Data sources for the disaggregated sectors

Domestic Intermediate Inputs, Final Demand and Output

Sector	JPN	CHN	AUS	KOR	USA	IND	BRZ	EU_25	EOG	I_M	ROW
Iro	JIO	CIO	AIO	USIOR	USIO	USIOR	JIOR	JIOR	USIOR	USIOR	JIOR
Ome	JIO	CIO	AIO	USIOR	USIO	USIOR	JIOR	JIOR	USIOR	USIOR	JIOR
Pio	JIO	WSY	WSY	WSY	WSY	WSY	WSY	WSY	WSY	WSY	WSY
Csb	JIO	WSY	WSY	WSY	WSY	WSY	WSY	WSY	WSY	WSY	WSY
Cse	JIO	WSY	WSY	WSY	WSY	WSY	WSY	WSY	WSY	WSY	WSY
Omn	JIO	CIO	AIO	AIO	USIO	USIOR	JIOR	JIOR	USIOR	USIOR	JIOR
Ssr	JWIO	JWIOR	JWIOR	JWIOR	USIO	USIOR	JWIOR	JWIOR	USIOR	USIOR	JIOR
Osr	JIO	JIOR	JIOR	JIOR	USIO	USIOR	JIOR	JIOR	USIOR	USIOR	JIOR

Bilateral Trade

Sector	Japan	China	Australia	Korea	USA	India	Brazil	EU_25	EOG	I_M	ROW
Iro	UN COMTRADE	IDE JETRO	IDE JETRO	IDE JETRO	UN COMTRADE and IDE JETRO	IDE JETRO	IDE JETRO and UN COMTRADE	IDEJETRO and UN COMTRADE	IDE JETRO	IDE JETRO	IDE JETRO
Ome	IDE JETRO	IDE JETRO	IDE JETRO	IDE JETRO	UN COMTRADE	UN COMTRADE	UN COMTRADE	IDEJETRO and UN COMTRADE	IDE JETRO	IDE JETRO	UN COMTRADE
Pio	IDE JETRO	IDE JETRO	IDE JETRO	IDE JETRO	IDE JETRO	IDE JETRO	IDE JETRO	UN COMTRADE	UN COMTRADE	IDE JETRO	UN COMTRADE
Csb	IDE JETRO	IDE JETRO	IDE JETRO	IDE JETRO	IDE JETRO	IDE JETRO	IDE JETRO	IDE JETRO and UN COMTRADE	IDE JETRO	IDE JETRO	UN COMTRADE
Cse	IDE JETRO	IDE JETRO	IDE JETRO	IDE JETRO	IDE JETRO	IDE JETRO	IDE JETRO	IDE JETRO and UN COMTRADE	IDE JETRO	IDE JETRO	UN COMTRADE
Omn	IDE JETRO	IDE JETRO	IDE JETRO	IDE JETRO	IDE JETRO	IDE JETRO	IDE JETRO	IDE JETRO	IDE JETRO	IDE JETRO	IDE JETRO
Ssr	UN COMTRADE	UN COMTRADE	UN COMTRADE	UN COMTRADE	UN COMTRADE	UN COMTRADE	UN COMTRADE	UN COMTRADE	UN COMTRADE	UN COMTRADE	UN COMTRADE
Osr	UN COMTRADE	UN COMTRADE	UN COMTRADE	UN COMTRADE	UN COMTRADE	UN COMTRADE	UN COMTRADE	UN COMTRADE	UN COMTRADE	UN COMTRADE	UN COMTRADE

Source: The authors.

Note:
- AIO = Australia's Input-Output Table
- CIO = China's input-Output Table
- IDE JETRO = Ratio is calculated using Global Trade Atlas Database compiled by IDE JETRO
- JIO = Japan's Input-Output Table
- JIOR = Calculated using the same ratios as Japan's Input-Output Table
- JWIO = Japan Waste Input-Output Table
- JWIOR = Calculated using the same ratios as Japan's Waste Input-Output Table
- USIO = The US Input-Output Table
- USIOR = Calculated using the same ratios as the US Input-Output Table
- WSY = World Steel Statistical Yearbook

Appendix A4

Table AA1 Source countries of CFs from iron ore sector (t CO_2)

	JPN	CHN	AUS	KOR	USA	IND	BRA	EU_25	I_M	EOG	ROW
JPN	1157.95	0	41.12	21.48	42.86	0.01	0.05	118.56	3.41	88.97	359.96
	(65.54%)	(0%)	(0.01%)	(1.02%)	(0.07%)	(0.02%)	(0.02%)	(0.02%)	(0%)	(0.01%)	(0.17%)
CHN	41.79	171069.70	715.91	254.40	2834.46	0.38	3.59	16064.36	34.62	7992.99	6950.32
	(2.37%)	(99.95%)	(0.13%)	(12.03%)	(4.90%)	(1.08%)	(1.40%)	(3.09%)	(0.04%)	(1.31%)	(3.25%)
AUS	131.29	12.03	0.53*	402.65	625.52	0.34	0.07	10678.27	9.20	10832.55	5359.85
	(7.43%)	(0.01%)	(98.96%)	(19.05%)	(1.08%)	(0.99%)	(0.03%)	(2.05%)	(0.01%)	(1.78%)	(2.51%)
KOR	0.22	0.04	0.62	176.32	1.27	0	0	3.67	0.23	26.41	22.58
	(0.01%)	(0%)	(0%)	(8.34%)	(0%)	(0%)	(0%)	(0%)	(0%)	(0%)	(0.01%)
USA	33.65	2.46	677.42	155.82	30826.40	0.10	13.31	13656.06	17.89	88996.13	8797.16
	(1.90%)	(0%)	(0.13%)	(7.37%)	(53.31%)	(0.28%)	(5.17%)	(2.62%)	(0.02%)	(14.61%)	(4.12%)
IND	38.30	25.98	339.88	86.37	265.50	28.95	0.10	7255.77	19.50	2147.05	6873.50
	(2.17%)	(0.02%)	(0.06%)	(4.09%)	(0.46%)	(82.93%)	(0.04%)	(1.39%)	(0.02%)	(0.35%)	(3.22%)
BRA	21.12	5.68	67.04	106.75	453.92	0.05	103.68	9806.83	7.25	4863.92	4084.10
	(1.20%)	(0%)	(0.01%)	(5.05%)	(0.79%)	(0.15%)	(40.29%)	(1.88%)	(0.01%)	(0.80%)	(1.91%)
EU_25	2.89	1.97	119.35	7.00	992.94	2.78	3.03	0.21*	9.87	10791.37	23013.74
	(0.16%)	(0%)	(0.02%)	(0.33%)	(1.72%)	(7.97%)	(1.18%)	(39.62%)	(0.01%)	(1.77%)	(10.77%)
I_M	78.70	1.72	853.87	198.91	35.97	0.52	0.01	5531.54	0.08*	112.38	8406.16
	(4.45%)	(0.00%)	(0.16%)	(9.41%)	(0.06%)	(1.48%)	(0%)	(1.06%)	(99.77%)	(0.02%)	(3.93%)
EOG	165.16	28.47	1482.33	437.90	19693.28	0.69	79.04	0.20*	44.67	0.45*	47805.69
	(9.35%)	(0.02%)	(0.27%)	(20.71%)	(34.06%)	(1.99%)	(30.71%)	(37.51%)	(0.05%)	(73.48%)	(22.37%)
ROW	95.79	7.85	1342.31	266.35	2050.50	1.08	54.46	55897.92	48.15	35758.17	0.10*
	(5.42%)	(0.00%)	(0.25%)	(12.60%)	(3.55%)	(3.10%)	(21.16%)	(10.74%)	(0.06%)	(5.87%)	(47.75%)

Note: * indicates the values are in Mt.

Table AA2 Source countries of CFs from pig iron sector (t CO_2)

	JPN	CHN	AUS	KOR	USA	IND	BRA	EU_25	I_M	EOG	ROW
JPN	6648.66	208.38	1040.04	775.63	1582.68	74.35	52.15	1730.49	12305.45	0.14*	0.23*
	(19.84%)	(0.02%)	(2.16%)	(14.43%)	(0.97%)	(0%)	(1.15%)	(0.14%)	(9.48%)	(0.62%)	(3.32%)
CHN	12582.08	0.92*	2810.50	1740.22	15190.35	255.76	377.89	25945.74	39709.73	0.43*	0.74*
	(37.55%)	(99.84%)	(5.83%)	(32.36%)	(9.26%)	(0.01%)	(8.35%)	(2.10%)	(30.59%)	(1.97%)	(10.88%)
AUS	131.19	15.30	36346.78	75.26	769.60	24.88	0.29	361.37	2708.65	2019.63	41854.24
	(0.39%)	(0.00%)	(75.35%)	(1.40%)	(0.47%)	(0%)	(0.01%)	(0.03%)	(2.09%)	(0.01%)	(0.62%)
KOR	2934.81	196.26	653.84	1105.99	2037.07	76.35	50.38	1787.25	6354.71	86548.75	91790.16
	(8.76%)	(0.02%)	(1.36%)	(20.57%)	(1.24%)	(0%)	(1.11%)	(0.14%)	(4.90%)	(0.39%)	(1.35%)
USA	380.69	50.47	202.25	130.58	61893.72	67.19	167.80	3643.83	2163.85	0.81*	66757.56
	(1.14%)	(0.01%)	(0.42%)	(2.43%)	(37.75%)	(0%)	(3.71%)	(0.30%)	(1.67%)	(3.67%)	(0.98%)
IND	801.84	61.79	282.67	108.24	6232.46	4.56*	60.46	11313.76	5357.03	0.10*	0.18*
	(2.39%)	(0.01%)	(0.59%)	(2.01%)	(3.80%)	(99.95%)	(1.34%)	(0.92%)	(4.13%)	(0.47%)	(2.70%)
BRA	713.36	49.82	63.47	147.90	9352.20	9.09	2091.96	6909.85	1562.32	0.15*	0.17*
	(2.13%)	(0.01%)	(0.13%)	(2.75%)	(5.70%)	(0%)	(46.24%)	(0.56%)	(1.20%)	(0.69%)	(2.45%)
EU_25	484.58	90.08	892.88	118.23	7463.53	240.90	604.93	1.03*	7122.07	0.59*	0.41*
	(1.45%)	(0.01%)	(1.85%)	(2.20%)	(4.55%)	(0.01%)	(13.37%)	(83.67%)	(5.49%)	(2.66%)	(5.96%)
I_M	372.01	25.48	1977.47	73.98	805.90	46.37	5.64	1700.88	6581.41	0.06*	0.11*
	(1.11%)	(0%)	(4.10%)	(1.38%)	(0.49%)	(0%)	(0.12%)	(0.14%)	(5.07%)	(0.27%)	(1.61%)
EOG	1034.56	148.18	211.00	501.52	41584.23	494.82	211.85	63024.76	4868.06	18.23*	0.93*
	(3.09%)	(0.02%)	(0.44%)	(9.33%)	(25.36%)	(0.01%)	(4.68%)	(5.11%)	(3.75%)	(82.66%)	(13.70%)
ROW	7420.61	630.78	3758.94	599.35	17054.20	769.16	900.34	84859.17	41059.52	1.45*	3.84*
	(22.15%)	(0.07%)	(7.79%)	(11.15%)	(10.40%)	(0.02%)	(19.90%)	(6.88%)	(31.63%)	(6.58%)	(56.44%)

Note: * indicates the values are in Mt.

Table AA3 Source countries of CFs from blast furnace crude steel sector (t CO_2)

	JPN	CHN	AUS	KOR	USA	IND	BRA	EU_25	I_M	EOG	ROW
JPN	3818.61	119.68	597.34	445.48	909.00	42.70	29.95	993.89	7067.54	0.08*	0.13*
	(20.94%)	(0.03%)	(1.77%)	(15.09%)	(1.17%)	(0%)	(1.50%)	(0.15%)	(10.07%)	(0.82%)	(3.49%)
CHN	6236.35	455984.70	1393.04	862.54	7529.15	126.77	187.30	12860.10	19682.27	0.22*	0.37*
	(34.20%)	(99.82%)	(4.14%)	(29.23%)	(9.66%)	(0.01%)	(9.36%)	(1.98%)	(28.04%)	(2.23%)	(9.88%)
AUS	98.57	11.49	27308.06	56.55	578.21	18.69	0.22	271.50	2035.06	1517.39	31445.93
	(0.54%)	(0%)	(81.11%)	(1.92%)	(0.74%)	(0%)	(0.01%)	(0.04%)	(2.90%)	(0.02%)	(0.85%)
KOR	2038.55	136.33	454.17	768.23	1414.97	53.03	35.00	1241.44	4414.06	60117.74	63758.48
	(11.18%)	(0.03%)	(1.35%)	(26.03%)	(1.81%)	(0%)	(1.75%)	(0.19%)	(6.29%)	(0.62%)	(1.72%)
USA	185.60	24.60	98.60	63.66	30175.14	32.76	81.81	1776.48	1054.94	0.4*	32546.42
	(1.02%)	(0.01%)	(0.29%)	(2.16%)	(38.70%)	(0%)	(4.09%)	(0.27%)	(1.50%)	(4.08%)	(0.88%)
IND	185.60	24.60	98.60	63.66	30175.14	32.76	81.81	1776.48	1054.94	0.4*	32546.42
	(1.62%)	(0%)	(0.31%)	(1.35%)	(2.95%)	(99.93%)	(1.12%)	(0.64%)	(2.82%)	(0.40%)	(1.83%)
BRA	234.87	16.40	20.90	48.69	3079.13	2.99	688.76	2275.01	514.38	50154.10	54745.20
	(1.29%)	(0%)	(0.06%)	(1.65%)	(3.95%)	(0%)	(34.42%)	(0.35%)	(0.73%)	(0.52%)	(1.47%)
EU_25	257.67	47.90	474.76	62.87	3968.55	128.09	321.66	548549.99	3786.98	0.31*	0.22*
	(1.41%)	(0.01%)	(1.41%)	(2.13%)	(5.09%)	(0.01%)	(16.08%)	(84.34%)	(5.39%)	(3.22%)	(5.80%)
I_M	162.02	11.10	861.24	32.22	350.99	20.20	2.46	740.78	2866.40	0.03*	0.05*
	(0.89%)	(0%)	(2.56%)	(1.09%)	(0.45%)	(0%)	(0.12%)	(0.11%)	(4.08%)	(0.27%)	(1.28%)
EOG	432.492	61.944	88.207	209.657	17384.041	206.858	88.562	26347.128	2035.063	7.62*	0.39*
	(2.37%)	(0.01%)	(0.26%)	(7.10%)	(22.29%)	(0.01%)	(4.43%)	(4.05%)	(2.90%)	(78.79%)	(10.49%)
ROW	4474.658	380.361	2266.656	361.412	10283.754	463.808	542.910	51170.453	0.02*	0.88*	2.31*
	(24.54%)	(0.08%)	(6.73%)	(12.25%)	(13.19%)	(0.03%)	(27.13%)	(7.87%)	(35.27%)	(9.05%)	(62.32%)

Note: * indicates the values are in Mt.

Table AA4 Source countries of CFs from electric arc furnace crude steel sector (t CO_2)

	JPN	CHN	AUS	KOR	USA	IND	BRA	EU_25	I_M	EOG	ROW
JPN	2006.36	62.88	313.85	234.06	477.60	22.44	15.74	522.21	3713.41	0.04*	0.07*
	(20.46%)	(0.05%)	(3.04%)	(11.37%)	(0.60%)	(0%)	(1.56%)	(0.14%)	(9.61%)	(0.34%)	(3.08%)
CHN	1687.90	123414.57	377.03	233.45	2037.80	34.31	50.69	3480.65	5327.11	0.06*	0.1*
	(17.21%)	(99.52%)	(3.65%)	(11.34%)	(2.55%)	(0%)	(5.03%)	(0.91%)	(13.78%)	(0.48%)	(4.49%)
AUS	22.79	2.66	6314.55	13.08	133.70	4.32	0.05	62.78	470.58	350.87	7271.37
	(0.23%)	(0.00%)	(61.15%)	(0.64%)	(0.17%)	(0%)	(0.01%)	(0.02%)	(1.22%)	(0%)	(0.33%)
KOR	2374.20	158.77	528.95	894.72	1647.95	61.77	40.76	1445.85	5140.83	0.07*	0.07*
	(24.21%)	(0.13%)	(5.12%)	(43.46%)	(2.06%)	(0%)	(4.04%)	(0.38%)	(13.30%)	(0.58%)	(3.36%)
USA	247.77	32.85	131.64	84.99	0.04*	43.73	109.21	2371.58	1408.33	0.53*	0.04*
	(2.53%)	(0.03%)	(1.27%)	(4.13%)	(50.43%)	(0%)	(10.83%)	(0.62%)	(3.64%)	(4.36%)	(1.96%)
IND	308.42	23.77	108.73	41.63	2397.27	1.75*	23.25	4351.75	2060.54	0.04*	0.07*
	(3.14%)	(0.02%)	(1.05%)	(2.02%)	(3.00%)	(99.96%)	(2.31%)	(1.14%)	(5.33%)	(0.33%)	(3.19%)
BRA	68.69	4.80	6.11	14.24	900.47	0.88	201.42	665.31	150.43	0.02*	0.02*
	(0.70%)	(0%)	(0.06%)	(0.69%)	(1.13%)	(0%)	(19.98%)	(0.17%)	(0.39%)	(0.12%)	(0.72%)
EU_25	144.31	26.83	265.89	35.21	2222.59	71.74	180.14	0.31*	2120.90	0.18*	0.12*
	(1.47%)	(0.02%)	(2.57%)	(1.71%)	(2.78%)	(0%)	(17.87%)	(80.32%)	(5.49%)	(1.44%)	(5.46%)
I_M	201.92	13.83	1073.32	40.15	437.42	25.17	3.06	923.19	3572.23	0.03*	0.06*
	(2.06%)	(0.01%)	(10.39%)	(1.95%)	(0.55%)	(0%)	(0.30%)	(0.24%)	(9.24%)	(0.27%)	(2.68%)
EOG	607.76	87.05	123.95	294.62	24428.82	290.69	124.45	37024.14	2859.76	10.71*	0.55*
	(6.20%)	(0.07%)	(1.20%)	(14.31%)	(30.58%)	(0.02%)	(12.34%)	(9.68%)	(7.40%)	(88.61%)	(24.75%)
ROW	2137.53	181.70	1082.77	172.65	4912.51	221.56	259.35	0.24*	0.02	0.42*	1.11*
	(21.79%)	(0.15%)	(10.49%)	(8.39%)	(6.15%)	(0.01%)	(25.73%)	(6.39%)	(30.60%)	(3.46%)	(49.98%)

Note: * indicates the values are in Mt.

Table AA5 Source countries of CFs from motor vehicle sector (Mt CO_2)

	JPN	CHN	AUS	KOR	USA	IND	BRA	EU_25	I_M	EOG	ROW
JPN	23.74	0.84	1.33	0.12	10.17	0.14	0.15	3.97	0.47	1.27	4.70
	(80.56%)	(1.35%)	(14.26%)	(0.84%)	(3.93%)	(0.80%)	(1.56%)	(2.06%)	(10.43%)	(1.97%)	(7.86%)
CHN	1.69	58.32	0.21	0.35	7.82	0.05	0.04	3.49	0.22	1.03	2.45
	(5.73%)	(94.57%)	(2.22%)	(2.37%)	(3.03%)	(0.29%)	(0.38%)	(1.81%)	(4.92%)	(1.59%)	(4.09%)
AUS	0.03	0.01	5.57	0.04	0.24	0	0.01	0.04	0.01	0.02	0.61
	(0.09%)	(0.02%)	(59.63%)	(0.30%)	(0.09%)	(0.02%)	(0.08%)	(0.02%)	(0.25%)	(0.03%)	(1.02%)
KOR	0.18	0.65	0.27	13.67	5.44	0.16	0.02	2.78	0.15	0.82	2.54
	(0.60%)	(1.06%)	(2.90%)	(93.70%)	(2.11%)	(0.95%)	(0.18%)	(1.44%)	(3.37%)	(1.26%)	(4.24%)
USA	0.80	0.25	0.46	0.12	176.61	0.05	0.32	3.86	0.02	17.61	2.48
	(2.73%)	(0.40%)	(4.89%)	(0.84%)	(68.31%)	(0.29%)	(3.40%)	(2.01%)	(0.49%)	(27.27%)	(4.14%)
IND	0.02	0.01	0.02	0.02	0.34	16.52	0.01	0.87	0.02	0.22	0.66
	(0.08%)	(0.01%)	(0.23%)	(0.12%)	(0.13%)	(96.06%)	(0.07%)	(0.45%)	(0.48%)	(0.35%)	(1.10%)
BRA	0.01	0.05	0.03	0.01	0.64	0.01	7.68	0.41	0.01	0.64	1.39
	(0.03%)	(0.08%)	(0.28%)	(0.10%)	(0.25%)	(0.08%)	(80.45%)	(0.21%)	(0.24%)	(0.99%)	(2.32%)
EU_25	1.94	1.14	0.72	0.22	11.06	0.15	0.56	170.84	0.11	3.08	9.72
	(6.59%)	(1.84%)	(7.69%)	(1.50%)	(4.28%)	(0.87%)	(5.83%)	(88.73%)	(2.56%)	(4.78%)	(16.25%)
I_M	0.13	0.03	0.02	0	0.11	0.01	0	0.21	3.07	0.03	0.34
	(0.44%)	(0.04%)	(0.21%)	(0.03%)	(0.04%)	(0.07%)	(0.05%)	(0.11%)	(68.91%)	(0.05%)	(0.57%)
EOG	0.10	0.12	0.12	0.01	44.71	0.01	0.08	1.00	0	38.60	1.46
	(0.34%)	(0.19%)	(1.28%)	(0.04%)	(17.29%)	(0.03%)	(0.89%)	(0.52%)	(0.06%)	(59.79%)	(2.44%)
ROW	0.83	0.27	0.60	0.02	1.37	0.09	0.68	5.06	0.37	1.23	33.50
	(2.82%)	(0.44%)	(6.41%)	(0.16%)	(0.53%)	(0.54%)	(7.11%)	(2.63%)	(8.28%)	(1.91%)	(55.98%)

Table AA6 Source countries of CFs from other transportation equipment sector (Mt CO_2)

	JPN	CHN	AUS	KOR	USA	IND	BRA	EU_25	I_M	EOG	ROW
JPN	2.9	24.2*	0.1	0.0	0.7	0.1	0.0	0.7	0.1	0.2	1.0
	(47.55%)	(0.06%)	(2.88%)	(1.33%)	(1.45%)	(0.56%)	(0.55%)	(1.90%)	(1.60%)	(1.32%)	(3.78%)
CHN	1.10	39.99	0.32	0.23	2.03	0.14	0.02	3.12	0.31	1.21	3.23
	(18.15%)	(99.01%)	(17.20%)	(10.61%)	(4.46%)	(1.27%)	(1.84%)	(8.23%)	(7.51%)	(9.31%)	(11.70%)
AUS	3.54*	0.3*	0.39	0.83*	0.05	4.19*	0.02*	0.03	2.68*	2.6*	0.08
	(0.06%)	(0.00%)	(20.60%)	(0.04%)	(0.11%)	(0.04%)	(0.00%)	(0.08%)	(0.06%)	(0.02%)	(0.30%)
KOR	0.01	0.01	1.99*	1.14	0.35	0.20	0.02*	1.22	0.05	0.49	3.17
	(0.21%)	(0.02%)	(0.11%)	(52.34%)	(0.77%)	(1.91%)	(0.02%)	(3.22%)	(1.24%)	(3.80%)	(11.47%)
USA	1.55	0.16	0.52	0.52	34.52	0.22	0.09	5.99	0.18	1.81	3.94
	(25.52%)	(0.41%)	(27.69%)	(23.78%)	(75.82%)	(2.10%)	(9.68%)	(15.82%)	(4.23%)	(13.89%)	(14.24%)
IND	2.04*	1.6*	2.02*	3.19*	0.04	9.39	1*	0.11	0.01	0.05	0.46
	(0.03%)	(0.00%)	(0.11%)	(0.15%)	(0.08%)	(87.69%)	(0.10%)	(0.30%)	(0.13%)	(0.40%)	(1.66%)
BRA	1.13*	0.01	3.43*	0.01	0.66	0.01	0.81	0.41	1*	0.12	0.10
	(0.02%)	(0.01%)	(0.18%)	(0.36%)	(1.44%)	(0.05%)	(82.43%)	(1.07%)	(0.03%)	(0.91%)	(0.38%)
EU_25	0.16	0.11	0.30	0.12	2.15	0.25	0.03	20.81	0.04	1.29	4.27
	(2.56%)	(0.28%)	(15.80%)	(5.40%)	(4.72%)	(2.33%)	(3.28%)	(54.95%)	(0.88%)	(9.90%)	(15.43%)
I_M	0.04	3.75*	0.06	0.01	0.05	0.02	0.8*	0.12	3.25	0.03	0.48
	(0.60%)	(0.01%)	(3.06%)	(0.47%)	(0.11%)	(0.17%)	(0.08%)	(0.33%)	(77.95%)	(0.22%)	(1.74%)
EOG	0.09	0.05	0.10	0.05	3.92	0.12	2.33*	1.68	0.02	6.93	1.39
	(1.49%)	(0.11%)	(5.19%)	(2.25%)	(8.60%)	(1.14%)	(0.24%)	(4.44%)	(0.53%)	(53.27%)	(5.04%)
ROW	0.23	0.03	0.14	0.07	1.11	0.29	0.02	3.65	0.24	0.90	9.47
	(3.80%)	(0.08%)	(7.19%)	(3.27%)	(2.43%)	(2.75%)	(1.77%)	(9.65%)	(5.83%)	(6.95%)	(34.26%)

Note: * indicates the values are in thousand tons.

Table AA7 Source countries of CFs from electronic equipment sector (Mt CO_2)

	JPN	CHN	AUS	KOR	USA	IND	BRA	EU_25	I_M	EOG	ROW
JPN	48.98	1.09	0.27	0.84	3.65	0.07	0.06	4.13	0.57	0.45	3.00
	(62.10%)	(1.66%)	(3.99%)	(4.99%)	(2.33%)	(0.47%)	(0.93%)	(3.19%)	(5.04%)	(1.26%)	(4.86%)
CHN	14.11	57.35	2.18	3.06	34.31	1.71	0.61	29.73	2.23	4.73	11.30
	(17.90%)	(87.19%)	(32.72%)	(18.10%)	(21.96%)	(11.10%)	(9.11%)	(22.98%)	(19.69%)	(13.21%)	(18.30%)
AUS	0.01	0.01	1.01	0	0.03	0.02	0.0004*	0.06	0.01	0.01	0.13
	(0.01%)	(0.01%)	(15.19%)	(0.02%)	(0.02%)	(0.11%)	(0.01%)	(0.04%)	(0.08%)	(0.02%)	(0.21%)
KOR	1.78	1.35	0.38	8.68	4.55	0.53	0.36	4.02	0.68	0.75	3.10
	(2.26%)	(2.05%)	(5.76%)	(51.28%)	(2.91%)	(3.45%)	(5.32%)	(3.11%)	(5.99%)	(2.09%)	(5.01%)
USA	2.43	0.59	0.50	1.45	77.90	0.43	0.71	7.65	1.40	8.40	4.25
	(3.08%)	(0.90%)	(7.56%)	(8.59%)	(49.86%)	(2.82%)	(10.68%)	(5.91%)	(12.34%)	(23.45%)	(6.88%)
IND	5751.63*	5232.4*	9667.4*	4571.58*	0.11	10.71	1363.14	0.27	0.05	0.03	0.18
	(0.01%)	(0.01%)	(0.14%)	(0.03%)	(0.07%)	(69.77%)	(0.02%)	(0.21%)	(0.45%)	(0.08%)	(0.28%)
BRA	2202.97*	2008.21*	1198.38*	1377.79*	0.11	1559.79*	4.30	0.10	557.85*	0.04	0.13
	(0.00%)	(0.00%)	(0.02%)	(0.01%)	(0.07%)	(0.01%)	(64.40%)	(0.07%)	(0.00%)	(0.11%)	(0.21%)
EU_25	0.42	0.28	0.22	0.21	1.87	0.27	0.19	62.01	0.53	1.64	3.82
	(0.53%)	(0.43%)	(3.32%)	(1.21%)	(1.20%)	(1.73%)	(2.80%)	(47.94%)	(4.67%)	(4.59%)	(6.19%)
I_M	2.98	1.56	0.94	0.41	8.61	0.56	0.07	4.86	2.27	0.61	5.44
	(3.77%)	(2.38%)	(14.15%)	(2.40%)	(5.51%)	(3.66%)	(1.07%)	(3.76%)	(20.02%)	(1.70%)	(8.81%)
EOG	0.28	0.13	0.12	0.07	15.45	0.07	0.09	1.79	0.09	17.21	0.99
	(0.35%)	(0.20%)	(1.74%)	(0.39%)	(9.89%)	(0.45%)	(1.38%)	(1.38%)	(0.76%)	(48.02%)	(1.61%)
ROW	7.88	3.40	1.03	2.20	9.64	0.99	0.29	14.75	3.51	1.96	29.42
	(9.99%)	(5.17%)	(15.39%)	(12.97%)	(6.17%)	(6.44%)	(4.29%)	(11.40%)	(30.97%)	(5.48%)	(47.64%)

Note: * indicate the values are in tons.

Table AA8 Source countries of CFs from other machinery and equipment sector (Mt CO_2)

	JPN	CHN	AUS	KOR	USA	IND	BRA	EU_25	I_M	EOG	ROW
JPN	41.78	4.68	0.33	1.15	6.03	0.19	0.21	3.83	0.75	1.10	7.95
	(57.45%)	(2.18%)	(3.02%)	(6.24%)	(2.20%)	(0.33%)	(2.03%)	(1.81%)	(8.30%)	(1.30%)	(6.06%)
CHN	17.32	186.11	1.87	1.57	34.07	1.01	0.92	23.97	2.36	7.49	26.26
	(23.82%)	(86.55%)	(17.19%)	(8.49%)	(12.44%)	(1.73%)	(8.93%)	(11.31%)	(26.27%)	(8.79%)	(20.02%)
AUS	0.06	0.08	4.54	0.01	0.30	0.02	0.01	0.30	0.06	0.08	0.70
	(0.08%)	(0.04%)	(41.81%)	(0.08%)	(0.11%)	(0.04%)	(0.10%)	(0.14%)	(0.66%)	(0.09%)	(0.54%)
KOR	1.05	4.93	0.18	13.70	1.78	0.21	0.09	1.90	0.27	0.95	2.77
	(1.44%)	(2.29%)	(1.63%)	(74.30%)	(0.65%)	(0.35%)	(0.86%)	(0.90%)	(3.04%)	(1.12%)	(2.11%)
USA	3.62	2.36	1.11	0.68	169.03	0.35	0.89	9.41	0.43	17.55	10.17
	(4.98%)	(1.10%)	(10.23%)	(3.68%)	(61.69%)	(0.59%)	(8.64%)	(4.44%)	(4.75%)	(20.60%)	(7.75%)
IND	0.17	0.15	0.09	0.02	1.27	55.01	0.05	1.16	0.10	0.46	2.07
	(0.24%)	(0.07%)	(0.78%)	(0.13%)	(0.46%)	(93.89%)	(0.48%)	(0.55%)	(1.13%)	(0.54%)	(1.58%)
BRA	0.02	0.04	0.02	0	0.63	0.01	6.01	0.32	0.01	0.32	1.03
	(0.02%)	(0.02%)	(0.16%)	(0.03%)	(0.23%)	(0.02%)	(58.47%)	(0.15%)	(0.14%)	(0.37%)	(0.78%)
EU_25	2.41	4.59	1.17	0.59	11.62	0.83	1.17	147.49	0.52	9.10	20.56
	(3.31%)	(2.13%)	(10.81%)	(3.18%)	(4.24%)	(1.42%)	(11.42%)	(69.58%)	(5.74%)	(10.68%)	(15.67%)
I_M	1.07	0.65	0.15	0.06	1.32	0.07	0.04	1.11	2.34	0.29	3.02
	(1.48%)	(0.30%)	(1.40%)	(0.35%)	(0.48%)	(0.12%)	(0.41%)	(0.52%)	(26.08%)	(0.34%)	(2.30%)
EOG	0.46	0.55	0.29	0.14	38.34	0.30	0.31	3.74	0.08	42.66	5.46
	(0.63%)	(0.25%)	(2.69%)	(0.79%)	(13.99%)	(0.50%)	(2.98%)	(1.76%)	(0.92%)	(50.06%)	(4.16%)
ROW	4.76	10.90	1.12	0.50	9.60	0.59	0.58	18.73	2.06	5.23	51.18
	(6.55%)	(5.07%)	(10.27%)	(2.74%)	(3.50%)	(1.01%)	(5.67%)	(8.84%)	(22.95%)	(6.13%)	(39.02%)

Table AA9 Source countries of CFs from construction sector (Mt CO_2)

	JPN	CHN	AUS	KOR	USA	IND	BRA	EU_25	I_M	EOG	ROW
JPN	148.45	0	0	0	0.08	0.03	0	0.55	0.05	0.30	0.24
	(97.91%)	(0%)	(0%)	(0%)	(0.02%)	(0.03%)	(0%)	(0.17%)	(0.09%)	(0.12%)	(0.08%)
CHN	0.46	989.19	0	0	0.09	0.06	0	1.26	0.08	0.28	0.38
	(0.30%)	(100.00%)	(0%)	(0%)	(0.03%)	(0.05%)	(0%)	(0.39%)	(0.15%)	(0.12%)	(0.12%)
AUS	0.02	0	34.08	0	0	0	0	0	0	0	0.01
	(0.02%)	(0%)	(99.97%)	(0%)	(0%)	(0%)	(0%)	(0%)	(0%)	(0%)	(0.00%)
KOR	0.03	0	0	63.48	0	0	0	0.01	0	0	0.01
	(0.02%)	(0%)	(0%)	(99.96%)	(0%)	(0%)	(0%)	(0%)	(0%)	(0%)	(0%)
USA	0.30	0	0	0	356.05	0.02	0	0.30	0.03	0.21	0.17
	(0.20%)	(0%)	(0%)	(0%)	(99.73%)	(0.02%)	(0%)	(0.09%)	(0.06%)	(0.09%)	(0.05%)
IND	0.06	0	0	0	0.01	103.80	0	0.16	0.01	0.04	0.05
	(0.04%)	(0%)	(0%)	(0%)	(0%)	(99.63%)	(0%)	(0.05%)	(0.02%)	(0.01%)	(0.02%)
BRA	0	0	0	0	0	0	25.38	0	0	0	0
	(0%)	(0%)	(0%)	(0%)	(0%)	(0%)	(99.92%)	(0%)	(0%)	(0%)	(0%)
EU_25	0.96	0	0	0.01	0.27	0.15	0	316.98	0.22	0.40	0.97
	(0.63%)	(0%)	(0%)	(0.01%)	(0.08%)	(0.14%)	(0%)	(98.51%)	(0.42%)	(0.17%)	(0.31%)
I_M	0.13	0	0	0	0.03	0.02	0	0.36	51.70	0.08	0.10
	(0.09%)	(0%)	(0%)	(0%)	(0.01%)	(0.02%)	(0%)	(0.11%)	(98.98%)	(0.03%)	(0.03%)
EOG	0.60	0	0	0	0.20	0.04	0	0.71	0.06	236.21	0.27
	(0.40%)	(0%)	(0%)	(0.01%)	(0.06%)	(0.04%)	(0.01%)	(0.22%)	(0.11%)	(99.22%)	(0.09%)
ROW	0.60	0	0.01	0.01	0.29	0.07	0.01	1.44	0.09	0.54	307.62
	(0.40%)	(0%)	(0.02%)	(0.02%)	(0.08%)	(0.07%)	(0.04%)	(0.45%)	(0.18%)	(0.23%)	(99.29%)