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Finding a Global Energy and Resource Network in a Product Supply Chain Using a Global Link Input–Output Model

By

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Abstract

Today's globalized national economies are embedded in structures associated with high CO_2 emissions both domestically and internationally. At the same time, measures to reduce these emissions are set to be introduced increasingly around the world. This study considers the policy implications of these two concurrent trends by focusing on the structural relationship between a country's economy and the global CO_2 emissions it induces. Taking Japan as a case study, the study develops the novel 'GLIO' model and uses it to calculate the CO_2 emissions of the global supply chain network supporting Japanese household consumption. The results show that 31% of the total emissions attributed to households are generated outside Japan, especially in China, the U.S., Saudi Arabia, the U.A.E. and Indonesia. The study also identifies the principal foreign countries and regions that need to be prioritized by individual sectors in Japan when monitoring import-export regulations and overseas CO_2 emissions policies.

Main Text

Energy resources are distributed unevenly throughout the world, with 75% of the world's petroleum, 58% of its coal and 76% of its natural gas buried in low-income and middle-income developing countries (*1*). Via international trade these resources are supplied to developed and emerging countries, where they are consumed in vast quantities, creating huge CO_2 emissions that are contributing to global warming, Of the 27.1 Gt (Gt=10^9 t) global CO_2 emissions in 2005, about two-thirds was emitted by a mere 10 countries (*2*). In addition to these energy resources, agricultural and industrial products are likewise distributed around the world via international trade networks. Since 1950 the value of global trade has continued to rise by an average of 6% per annum, amounting in 2006 to 11,783 billion dollars (*3*). The trade in agricultural and industrial products naturally involves the international movement of the substances these products comprise (*4–6*). Meanwhile, although the environmental burden generated and water consumed during production of these products do not actually move between countries, there is an increasingly common perception that countries importing such products are thereby imparting environmental burdens and participating in resource consumption in the country of origin (*7–9*). If the CO_2 generated in the exporting country were to be counted as moving into the importing country together with the products, the emissions of Japan, the United States, Germany, the United Kingdom, Italy and South Korea, which are among the 10 countries cited earlier, become even greater than currently calculated, further increasing their share in global emissions (*7–8*). The implication is that economies have become more globalized and that the economic activities of developed countries, in particular, are now embedded in structures associated with high CO_2 emissions both domestically and internationally.

Meanwhile, 2008 marks the beginning of the first commitment period of the Kyoto Protocol, and new efforts to reduce greenhouse gas emissions by Japan, Europe and other parties to the protocol are bound to elicit public attention. In July 2008 the countries that participated in the G8 Hokkaido Toyako Summit (*10*) agreed to set a goal of reducing global greenhouse gas emissions by at least 50% by 2050. In addition to technological development, in the future an increasing number of countries are expected to implement carbon taxes, carbon trading and other major policies to control greenhouse gases (*11*).

Given the globalized carbon emissions associated with national economies and the anticipated acceleration of carbon control measures throughout the world, what does the concurrent progress of these two trends imply for individual national economies? This paper considers the policy implications of these trends by focusing on the structural relationships between national economies and global CO_2 emissions, thereby taking Japan as a case study. By viewing these globalized emissions from a different vantage point, it becomes apparent that a country's production and consumption systems cannot exist without CO_2 emissions outside the country, which can be interpreted as dependence on overseas emissions. Consequently, any country relying on other countries for its energy resources and agricultural and industrial products would be affected in its domestic production and consumption by any inconsistency or interruption in the import of such resources and products. The current state of affairs, in which soaring crude oil and cereal prices have inflicted serious damage on companies and households in many countries, provides a characteristic example. In a similar vein, any restrictions imposed overseas on CO_2 emissions, such as emission caps and carbon taxes, may well threaten the stability of economic activities in those countries relying heavily on other countries for their CO_2 emissions. Cases in point include the RoHS Directive (*12*) and REACH Regulation (*13*) enacted in EU member states, which have compelled sweeping changes in the production systems and product designs of countries outside the EU. Changes in environmental policy or enforcement of new regulations in one country can and do force considerable changes in the production and consumption processes of other countries.

Given these real experiences, we consider it important for those countries relying heavily on others for their CO_2 emissions to implement risk management strategies vis-à-vis global warming policies around the world. In other words, while steadily reducing their own emissions, these countries will need to develop policy-based and technological measures in advance to avoid or mitigate the effects of other countries' measures to address global warming. Achieving this goal will have to be based on an adequate understanding of the measurement and mechanisms of domestic and overseas CO_2 emissions arising through a country's production and consumption activities.

To this end, this study develops an accounting framework describing the complex global supply chains feeding into Japan's production and consumption system and a model to measure the CO_2 emitted in Japan and in foreign countries by way of those supply chains. Subsequently, the international network implicitly constituted by Japan's consumption through its reliance on other countries for its CO_2 emissions is articulated. In addition, the study seeks to interpret the structural characteristics of this network. As an initial step in elaborating a risk management strategy for Japan with respect to international global warming policies, this study furthermore identifies those countries and regions that merit particular attention when it comes to monitoring trends in CO_2 emission policies.

World input-output models (*14*) extended from an input-output model (*14–16*) are a useful tool for measuring the CO_2 emissions generated beyond the borders of a country by its domestic production and consumption. They have been widely used around the world, as reported by Weidmann (*17*). One advantage of using world input-output models is that they help identify the CO_2 emissions associated with the foreign production activities induced by domestic consumption in a particular country. Constructing data that describe domestic and international transactions of goods and services nevertheless involves serious challenges. The number of countries and production sectors that can realistically be considered in the world input-output system are limited. In particular, development of detailed data on countries producing oil and mineral resources, on which Japan relies for much of its imports, proves to be a complex task. Conventional world input-output models are incapable of facilitating analyses involving such countries. This study has consequently developed a novel analytical model: the GLIO model (*18*). This model is intended to identify the global structure of international relations, thereby incorporating the overseas sectors of over 200 countries and regions based on CO_2 emissions, and taking the consumption and production structure of Japan as a detailed configuration of approximately 800 sectors. The data required for the model were derived from statistics for the year 2000 (*19–24*). The analyses in this paper focus on household consumption activities inducing around 50% of Japan's domestic CO_2 emissions (*25*).

The total CO_2 emissions attributable to household consumption in Japan in 2000 were estimated at 939 Mt (Mt=10^6 t). As depicted in Fig. 1-a, 172 Mt (18%) of this total represents the direct CO_2 emissions due to combustion of fuels like gasoline and city-supplied gas in the household sector, 476 Mt (51%) the amount emitted within Japan at the production stage of commodities consumed by households, and 291 Mt (31%) the emissions outside the country attributable to imported goods demanded directly and indirectly in household consumption. Of this 291 Mt, 155 Mt (17% of the total) corresponds to the overseas emissions induced by the imported goods required for producing domestic products and 136 Mt (14%) to the overseas emissions caused by imported goods purchased directly for household consumption.

A breakdown of the 155 Mt (17%) overseas emissions is provided in Figure 1-b, which shows the 20 countries and regions with the largest emissions induced directly and indirectly by the production of domestic products, along with the remaining countries and regions, as “others.” This breakdown reveals that China, a country with strong economic ties with Japan, contributes 2.8% and the U.S. 1.6% of total emissions. In terms of monetary value, the U.S. accounts for the greatest share of the imports used for producing domestic products, 17%, followed by China, with 8.5%. In terms of their share in induced CO_2 emissions, however, the order is reversed, reflecting differences between the two countries with regard to emissions structure. Furthermore, Saudi Arabia (1.7%), the United Arab Emirates (U.A.E) (1.7%), Indonesia (1.5%), Iran (1.3%), Russia (0.98%), Qatar (0.95%) and other countries exporting fossil fuel resources like crude oil and natural gas rank relatively high in terms of these induced emissions. The salient implication is that Japan’s extremely high reliance on imported fossil fuel resources is leading to substantial emissions of carbon dioxide in these resource-exporting countries. Calculated thus, the Republic of South Africa’s contribution becomes 0.19%, exceeding that of European countries like the U.K., France and Germany, which in monetary terms have a greater share in Japanese imports (respectively 1.4%, 1.4% and 2.2%) than South Africa (0.76%). This implies that when it comes to the inputs used for producing its domestic output, Japan has stronger economic ties with South Africa than might initially be supposed.

Meanwhile, Fig. 1-c provides a breakdown of the 136 Mt (14%) emissions associated with the imported goods purchased directly by household consumers. Now, China accounts for more than half, at 8.1%, suggesting that the import of final consumer goods from China, rather than intermediate goods, has the greater emissions-inducing effect. China is followed by the U.S. (1.1%) and Russia (0.60%). With these countries, though, these amounts are less than their respective contributions to emissions via imports of intermediate goods. Also noteworthy are the large shares of emissions of eastern Asian and Southeast Asian countries (Thailand (0.46%), South Korea (0.45%), Indonesia (0.35%), Malaysia (0.26%) and Taiwan (0.25%)), which are geographically close to Japan, demonstrating a CO_2-related structure that differs considerably from that associated with the import of intermediate goods, in which countries exporting fossil fuel resources rank high.

What this study has also analyzed, in particular, is the process of overseas CO_2 emissions generated in the supply chains of domestic production underlying household consumption, the foundation of the Japanese economy. To this end, the structure of linkages with other countries and regions formed implicitly by household consumption via the domestic production sector was embodied as networks based on CO_2 emissions, comprising either a network between a Japanese domestic production sector and an overseas sector, or between one overseas sector and another (*18*). In this study, such a network is termed the Global Supply Chain Network on a CO_2 emission basis (GSCN-CO_2). To assist understanding of the structure of GSCN-CO_2, we focus in particular on two sub-networks in GSCN-CO_2, one representing the networks between Japan's domestic production sectors and overseas sectors, the other those among overseas sectors. From among the former networks included in GSCN-CO_2, Fig. 2-a portrays the top 30 networks generating the greatest of CO_2 emission. (*18*). These networks account for approximately 49% of all the CO_2 emitted by this class of networks included in our analysis. Such networks embody important relations underlying the supply of domestic products for household consumption in Japan. If the CO_2 emissions of the processes represented by these networks were restricted in any way, it would threaten the stability of the import of raw materials and products required for generating domestic output, with a potentially severe impact on both companies and consumers. Within the 10 highest-ranked networks (indicated by red arrows), a strong network between the sector "#138 Petroleum refinery products" and oil-producing countries such as Saudi Arabia, the U.A.E., Iran, Qatar, Kuwait and Indonesia is apparent. Other strong networks are those between "#292 Electric power for enterprise use" and Indonesia, between "#387 General eating and drinking places (except coffee shops)" and China, between "#295 Gas supply" and Indonesia, and between "#138 Petroleum refinery products" and China. Key countries and regions involved in the top 30 networks include the U.S., the U.A.E., Iran, Indonesia, Australia, Saudi Arabia, Malaysia, Russia, China, Qatar, Kuwait, Iraq, Oman, Vietnam and Brunei. Any export regulations imposed on CO_2 emissions by these countries and regions would therefore lead to restrictions on the emissions associated with these networks, with a resultant impact on household consumption in Japan. Exports are also intimately related to regulations within the exporting country, and any implementation of CO_2 emission controls, certification rules, carbon taxes or other regulations in that country would be bound to affect consumption in Japan to some extent. It is important, therefore, that Japanese government specifically examines trends relating to CO_2 emissions, export and domestic regulations.

In certain countries and regions, trends in import regulations related to CO_2 emissions will be of major influence on Japan's household consumption. These countries were also identified in this study, as shown in Fig. 2-b. This figure shows the top 30 networks from among the second class of sub-networks of GSCN-CO_2, i.e. these among overseas sectors, accounting for approximately 29% of the all the CO_2 emitted by these sub-networks. The top 10 networks (again in red) comprise those from China to the U.S., from China to the U.A.E., from India to the U.A.E., from the U.S. to Canada, from China to Hong Kong, from Canada to South Korea, from Russia to China, from China to Malaysia and from the U.S. to Malaysia. These networks constitute the principal international relations supporting the domestic supply of products for household consumption in Japan, and any imposition of restrictions on CO_2 emissions attributable to these networks might therefore affect that consumption indirectly. In other words, the destinations of the networks can be considered to be the countries that would threaten stability of supply of the goods and services consumed by Japanese households if requirements such as payment of tariffs and acquisition of CO_2 emissions certification were imposed on their imports. The importing countries involved in the top 30 networks include the U.S., the U.A.E., Iran, Indonesia, Australia, Oman, Canada, Saudi Arabia, Singapore, Thailand, Germany, Malaysia, Mexico, Russia, South Korea and China. Understanding trends in import regulations and formulating measures to address any import regulations related to CO_2 emissions in such countries are extremely important for establishing stable production and consumption systems in Japan.

By analyzing each type of domestic product in the manner described above, overseas CO_2 emissions can be quantified and countries and regions where regulations and policies relating to CO_2 emissions should be given attention can be identified for each production sector supporting Japanese household consumption. Table 1 presents a list of 15 domestic product sectors with a high percentage of overseas CO_2 emissions induced by households via consumption of domestic products. For each sector the table also lists the five countries and regions with the greatest emissions in this respect. The consumption category with the highest percentage of overseas emissions is "#183 Rolled and drawn aluminum." Of the annual emissions of 189 kt (1 kt=10^3 t), 39 kt is accounted for by domestic emissions and 149 kt by overseas emissions, indicating a large overseas share of 79%. The main emitting countries include Russia (39%), Australia (6%), Ukraine (6%), China (4%) and South Africa (4%), from which most aluminum metal is imported to Japan. The next is “#276 *Tatami* (straw matting) and straw products,” whose emissions are low at 77 kt, of which, however, 77% is emitted abroad. The emitting countries are China (55%), Australia (4%), the U.S. (4%), North Korea (3%) and Russia (1%), reflecting the fact that a large fraction of the raw materials for these products is produced in China. Overseas emissions of "#138 Petroleum refinery products” and “#294 Gas supply,” which rely for their raw materials on imports of crude oil and LNG, also rank high, at 70%, clearly reflecting the high emissions in countries producing oil and exporting natural gas. The sixth from the top, “#146 Leather footwear,” shows overseas emissions of 67% of the 1,023 kt concerned, with major emitting countries including Italy (2%). The following category, “#223 Personal computers”, has an overseas share of 66% out of 3,248 kt, which includes countries, such as the U.S. (11%), China (11%), South Korea (7%), Taiwan (6%) and Malaysia (5%), manufacturing CPUs, motherboards and other computer components. China, the U.S. and oil-producing countries rank high in terms of their share in the embodied emissions associated with overall household consumption, but for certain individual production sectors, Latin American and European countries also supply goods and services embodying substantial CO_2 emissions, such as Denmark (3%), ranking as fifth largest emitter for “#36 Processed meat products,” India (9%), ranking third, and Chile (6%), fourth, for “#178 Other non-ferrous metals”, and Brazil (3%), ranking fourth for “#54 Vegetable oils and meal”. These results not only demonstrate the quantitative dependence of Japanese household consumption on global CO_2 emissions; they also suggest that each production technology forms its own GSCN-CO_2 and that identifying the networks important to each production sector is extremely beneficial for strategic management of production technologies.

As an example, consider the GSCN-CO_2 formed by household consumption of "#183 Rolled and drawn aluminum", which has the highest share of overseas emissions. Similarly to the above analysis, we here focus on two sub-networks in GSCN-CO_2. Fig. 3-a shows the top 30 networks generating the highest CO_2 emissions in the class of sub-networks representing relations between domestic product sectors and overseas sectors. These top 30 networks account for 51% of the total CO_2 emitted in these sub-networks. Fig. 3-b, for its part, shows the top 30 networks in the class of sub-networks constituted by relations among overseas sectors, accounting for 96% of total CO_2 in these sub-networks. In the relations between overseas and domestic sectors depicted in Fig. 3-a, networks with countries supplying aluminum, such as Russia, Australia, Ukraine and South Africa, feature prominently in the production of "#183 Rolled and drawn aluminum", proving to be be key countries underpinning production of such products in terms of internationally embodied emissions Regarding the networks among overseas sectors, Fig. 3-b indicates that the countries configured around aluminum-producing countries like Russia and Australia constitute a strong CO_2 network. Together, this information suggests that producers of "#183 Rolled and drawn aluminum" in Japan need to prioritize those countries forming strong networks in Fig. 3-a, including Russia, Australia, Ukraine, South Africa and China, and monitor trends in their export regulations and domestic policies relating to CO_2 emissions. At the same time, those countries building strong networks in Fig. 3-b, including Russia, Ukraine, Australia, Canada and Belarus, should be given priority when Japanese producers of "#183 Rolled and drawn aluminum" monitor international trends in import controls. In this way, they will be preparing these foreign countries for changes in such policies and regulations and helping them establish a stable production system.

For other domestic production sectors supplying goods and services to household consumers in Japan, this study has also used the above method to identify the countries whose carbon policy should be given priority attention by each sector (*18*).

Management and control of CO_2 emissions require global efforts, involving regulations in individual countries as well as international agreements. As indicated by this study, however, the key to achieving both a low-carbon global society and economic stability in individual nations is to understand the present complex structure of the CO_2 emissions induced abroad by the consumption and supply of goods and services in each respective nation. This will enable legal and technological systems to be established that can be adapted to future changes in international trends regarding CO_2 emissions and their control. The global carbon networks (GSCN-CO_2) newly developed in this study provide fundamental data to facilitate such efforts. Careful observation and interpretation of trends in these networks are issues that need to be addressed urgently by governments, producers and consumers, as the first step in supply chain management that incorporates externalities like future CO_2 emissions.

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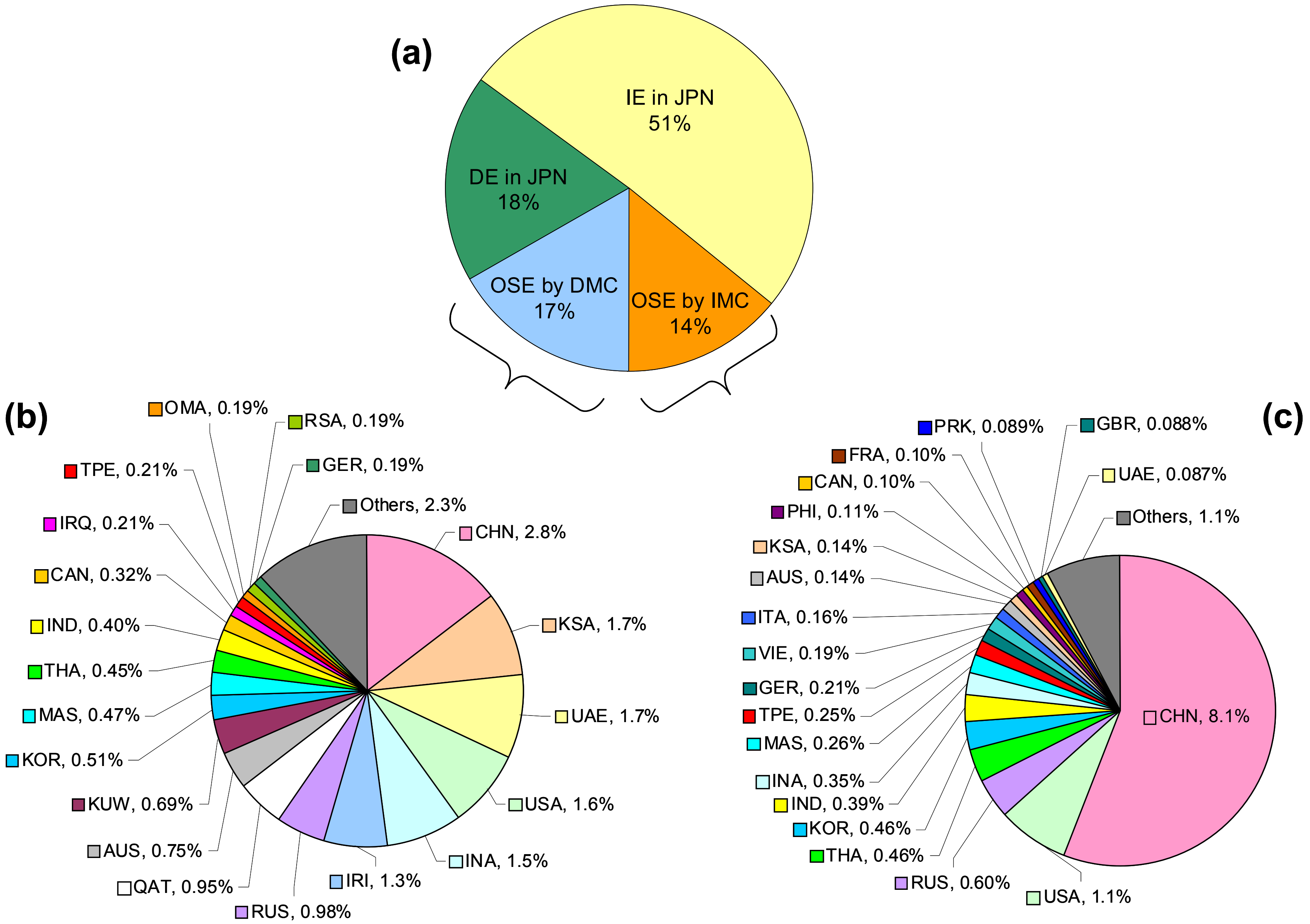
Table 1

Sector no.	Com no.	Sector name	Induced CO_2 emissions [kt/y]			Overse as share	Main emitting countries and regions
			In Japan	Overseas	Total	%	(%)
184	183	Rolled and drawn aluminum	39	149	189	79	RUS(39), AUS(6), UKR(6), CHN(4), RSA(4)
277	276	*Tatami* (straw matting) and straw products	12	42	55	77	CHN(55), AUS(4), USA(4), PRK(3), RUS(1)
139	138	Petroleum refinery products (incl. lubricants)	12770	30242	43011	70	KSA(14), UAE(13), IRI(13), QAT(6), KUW(5)
295	294	Gas supply	1564	3669	5232	70	INA(23), QAT(9), MAS(7), UAE(6), AUS(5)
276	275	Jewelry and adornments	153	312	466	67	CHN(17), RUS(13), INA(5), KOR(4), AUS(4)
147	146	Leather footwear	342	681	1023	67	CHN(33), USA(5), RSA(3), KOR(2), INA(2)
224	223	Personal computers	1115	2133	3248	66	USA(11), CHN(11), KOR(7), TPE(6), MAS(5)
37	36	Processed meat products	881	1658	2539	65	USA(17), CHN(14), AUS(7), CAN(4), DEN(3)
71	70	Animal feed	270	453	723	63	USA(21), CHN(8), CAN(6), AUS(5), THA(2)
265	264	Cameras	236	390	625	62	CHN(25), USA(7), THA(4), INA(3), MAS(3)
179	178	Other non-ferrous metals	22	33	55	60	AUS(12), INA(9), IND(7), CHI(6), RSA(4)
219	218	Electric audio equipment	1934	2603	4537	57	CHN(21), USA(6), KOR(5), MAS(4), INA(3)
55	54	Vegetable oils and meal	281	373	654	57	USA(23), CHN(10), CAN(5), BRA(3), AUS(2)
226	225	Electronic computing equipment (accessory equipment)	111	135	245	55	USA(10), CHN(9), KOR(5), MAS(5), TPE(4)
263	262	Bicycles	119	141	260	54	CHN(30), RUS(5), TPE(4), USA(2), INA(2)



(a)
IE in JPN 51%
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OMA, 0.19%
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TPE, 0.21%
GER, 0.19%
Others, 2.3%
IRQ, 0.21%
CHN, 2.8%
CAN, 0.32%
IND, 0.40%
KSA, 1.7%
THA, 0.45%
MAS, 0.47%
UAE, 1.7%
KOR, 0.51%
KUW, 0.69%
USA, 1.6%
AUS, 0.75%
INA, 1.5%
IRI, 1.3%
QAT, 0.95%
RUS, 0.98%
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CAN, 0.10%
UAE, 0.087%
PHI, 0.11%
Others, 1.1%
KSA, 0.14%
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GER, 0.21%
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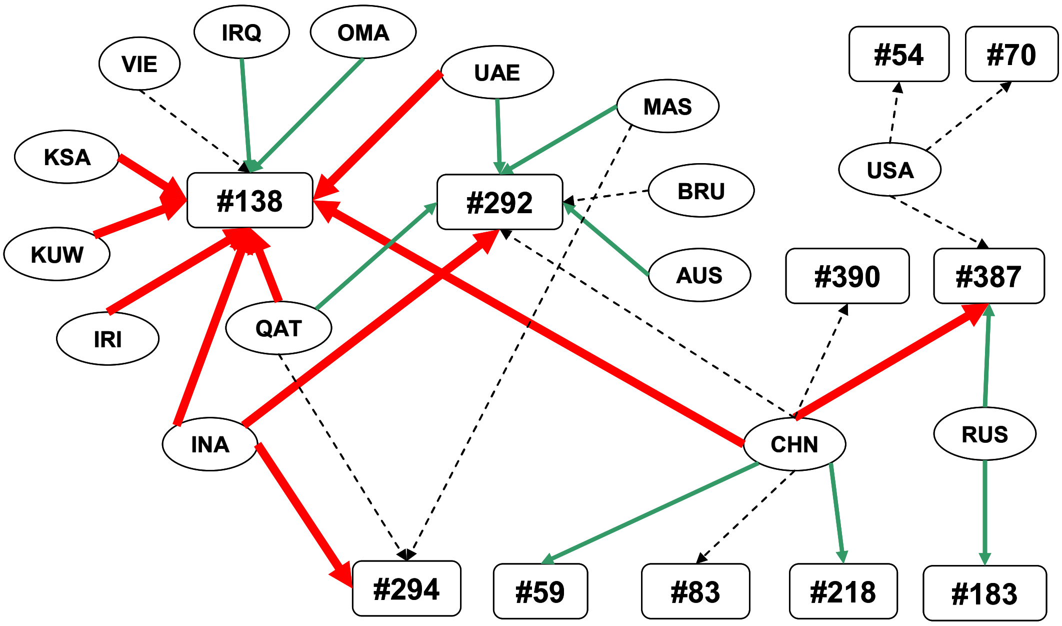
Figure 1



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(a)

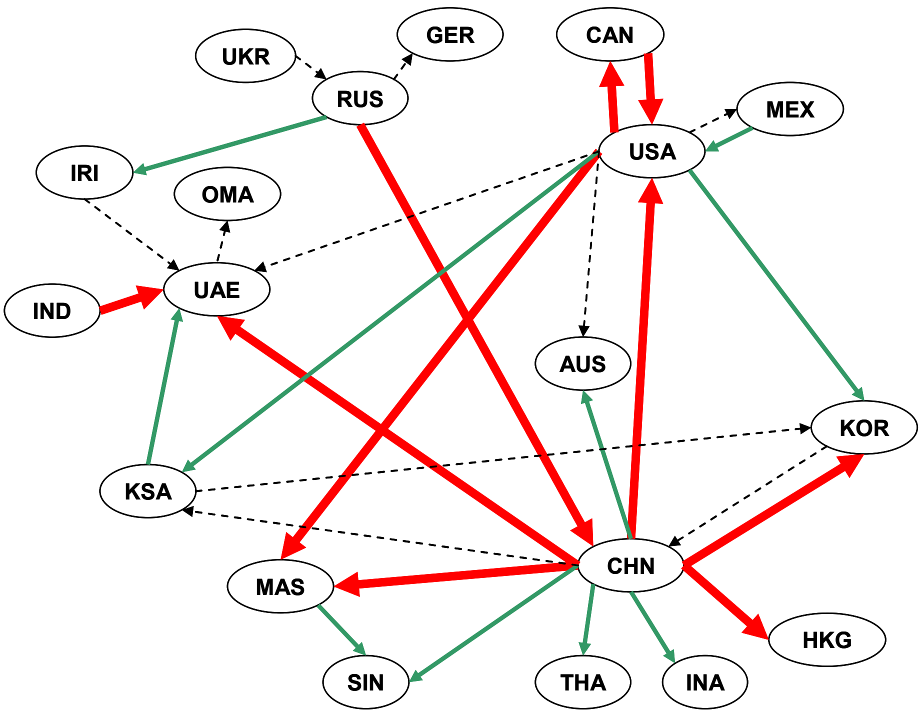

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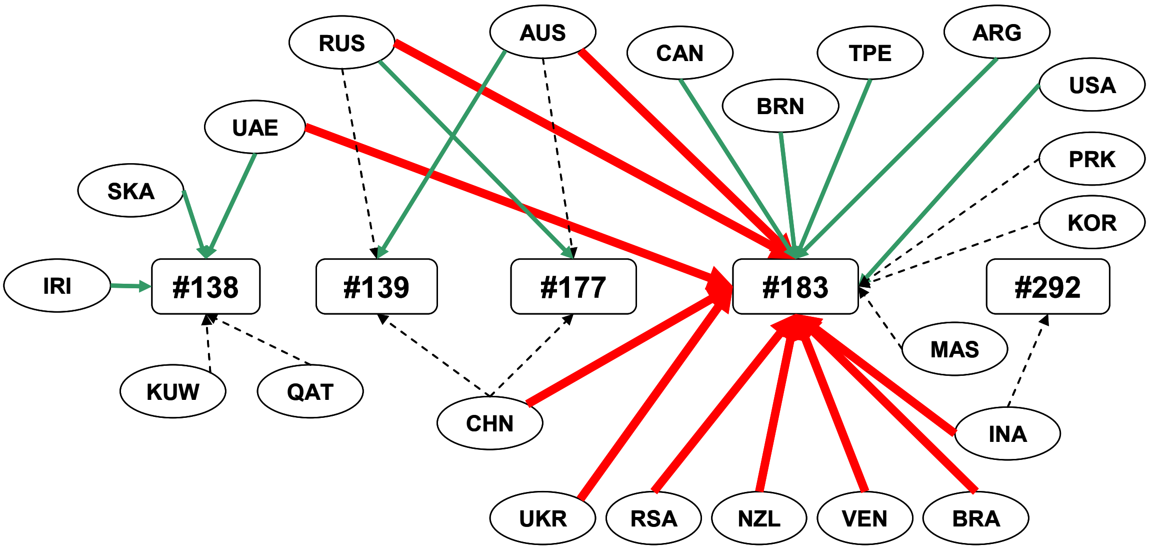
Figure 2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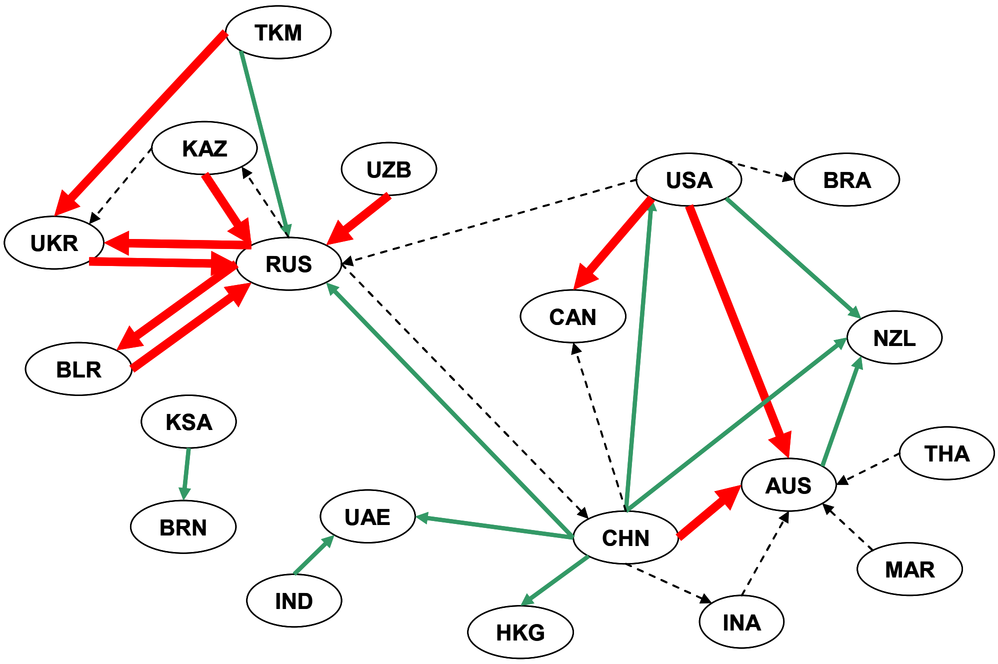
(a)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(b)

Figure 3

Legends

Table 1 Top 15 Japanese domestic commodities in terms of overseas share in total CO_2 emissions associated with supply of the commodity to household consumers in 2000. Country codes are as follows: AUS, Australia; BRA, Brazil; CAN, Canada; CHI, Chile; CHN, China; DEN, Denmark; INA, Indonesia; IND, India; IRI, Iran; KOR, South Korea; KSA, Saudi Arabia; KUW, Kuwait; MAS, Malaysia; PRK, North Korea; QAT, Qatar; RSA, South Africa; RUS, Russia; THA, Thai; TPE, Chinese Taipei; UAE, United Arab Emirates; UKR, Ukraine; USA, United States.

Figure1 **(a)** Shares of domestic and overseas CO_2 emissions associated with Japanese household consumption in 2000: DE, direct emissions; IE, indirect emissions; OSE, overseas emissions; DMC, consumption of domestic commodities; IMC, consumption of direct import commodities. **(b)** Share of countries in overseas emissions induced by household consumption of domestic commodities. **(c)** Share of countries in overseas emissions induced by household consumption of direct import commodities. Country codes aside from those in Table 1 are as follows: FRA, France; GBR, Great Britain; GER, Germany; IRQ, Iraq; ITA, Italia; OMA, Omen; PHI, Philippine; VIE, Vietnam.

Figure2 Top 30 global supply chain networks on a CO_2 emissions basis constituted indirectly by Japanese household consumption in 2000: **(a)** network from a foreign country to Japan's commodity sector; **(b)** network among foreign countries. The red arrows indicate the networks with the 10 highest emission levels, the green arrows those ranking 11^{th} to 20^{th} and the black dashed line those ranking 21^{st} to 30^{th}. Commodity numbers in (a) represent #54 Vegetable oils and meal, #59 Dishes, *sushi* and lunch boxes, #70 Animal feed, #83 Woven fabric apparel, #138 Petroleum refinery products (incl. lubricants), #183 Rolled and drawn aluminum, #218 Electric audio equipment, #292 Electric power for enterprise use, #294 Gas supply, #387 General eating and drinking places (except coffee shops) and #390 Hotel and other lodging places. Country codes aside from those in Table 1 and Fig. 1 are as follows: BRU, Brunei; HKG, Hong Kong; MEX, Mexico; SIN, Singapore.

Figure3 Top 30 global supply chain networks on a CO_2 emission basis constituted indirectly by production of the rolled and drawn aluminum commodity feeding into Japanese household consumption in 2000: **(a)** the network from a foreign country to

Japan’s commodity sector; **(b)** the network among foreign countries. Commodity numbers in **(a)** represent #138 Petroleum refinery products (incl. lubricants), #139 Coal products, #177 Aluminum (incl. regenerated aluminum), #183 Rolled and drawn aluminum, #292 Electric power for enterprise use. Country codes aside from those in Table 1 and Figs. 1 and 2 are as follows: ARG, Argentine; BLR, Belarus; BRN, Bahrain; KAZ, Kazakhstan; NZL, New Zealand; TKM, Turkmenistan; UZB, Uzbekistan; VEN, Venezuela