Embodied Energy and CO₂ Associated with Buildings by Using Input and Output Table in Japan

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Abstract: In July 2009, the 2005 basic Japanese input/output table was publicized together with its physical transaction table. This research paper analyzed the 2005 IO (input/output) table to create building industry-related intensities and, at the same time, compared the building industry with industries at large for distribution margins and transportation. The analysis of distribution margins separately for middle and purchaser margins found that middle margins in the building industry are minor at 35% of the averages for all industries, while purchaser margins are sizable at 1.8 times, proving that it is an industry for which local production for local consumption is quite effective. CO₂ emissions resulting from transportation in the building industry were calculated and concisely characterized. Although the ratio of transportation CO₂ emissions to total CO₂ emissions in each industry finds almost no difference between general industries and the building industry, transportation CO₂ emissions per production value are two to three times heavier than those from general industries to be justified as a transportation-intensive industry.

Key words: Embodied energy, embodied CO₂, input and output table.

Nomenclature

Input and output tables	The input/output tables are systematically present and clarify all the economic activities being performed in a single country, showing how goods and services produced by a certain industry in a given year are distributed among the industry itself, other industries, households, etc., and presenting the results in a matrix format	Embodied CO ₂	The sum of fuel related and non-fuel related CO ₂ emissions required directly and indirectly in all activities associated with the provision of goods or service, including the amounts emitted in all upstream processes
Input and output analysis	The use of national economy and energy, and CO ₂ data in a model to derive national average embodied energy/CO ₂ data in a comprehensive framework	Energy intensity	The total energy embodied, per unit of a product. This paper applied to per consumer price of a product
Embodied energy	The energy required directly and indirectly in all activities associated with the provision of goods or service, including the amounts consumed in all upstream processes	CO ₂ intensity	The total energy embodied, per unit of a product. This paper applied to per consumer price of a product
		Margins	Margins occurring when final construction materials are input into building sectors and defined as purchaser margins in this paper. Distribution margins are occurring among various industries resulting from production together with purchaser margins. This paper defines these distribution margins as middle margins

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1. Introduction

In July 2009, the 2005 basic Japanese input/output

table was publicized together with its physical transaction table [1]. This paper analyzes this IO (input/output) table and calculates CO₂ emissions and fossil fuel consumption by industrial sector resulting from 1 million yen's worth of production. The authors analyzed every 5-year inter-industrial relationship up to 2000 from the 1960 input/output table and identified a change over the years in the intensities of carbon dioxide [2, 3], thereby indicating that the reduction of CO₂ emissions caused by construction is greatly influenced by the intensities of carbon dioxide subject to a change in the entire industrial structure of Japan, despite the indicated effectiveness of a design contrivance. Thus, based on the idea that the latest intensities are indispensable for design, this paper was brought to a conclusion.

The 2005 IO table contains distribution margins by industrial sector to be input into the building sector (residential/wooden, residential/non-wooden, non-residential/wooden, non-residential/non-wooden) that has not been conducted in previous IO tables. With distribution margins considered as an issue directly involved in local production for local consumption, distribution margins and CO₂ emissions resulting from construction activities were collated. Since physical transactions by industry from 1 million yen's worth of production are also contained in the data, it was determined that energy consumption and CO₂ emissions caused by construction could be calculated, using producer's and purchaser's price-based type intensities by business identified in this paper.

In Japanese research papers concerning distribution margins of buildings, the energy used in the transportation of materials such as steel, ready-mixed concrete and wood has been reported [4-7]. Imada et al. [4] reviewed existing studied and inventory databases, and summarized type of methodology of each database to obtain energy consumption and CO₂ emissions due to transportation process. Ikaga et al. [5] conducted a survey on the imported wood products, and obtained CO₂ intensities due to wood products transportation,

and reported CO₂ emissions of imported woods products due to transportation occupy 30%-40 % of total CO₂ emission of wood products' whole process from production process to construction site. Amano et al. [6] conducted IO analysis and process analysis on cement and concrete products, and reported that CO₂ emissions due to transportation occupy about 12% of total CO₂ emission of concrete products from production process and construction site. Yamabe et al. [7] performed a simulation of circulation type of steel products in a society and showed that 173,015~199,406 t-CO₂ for transportation of 1,180,080 t steel products.

Overseas, Cole [8] and Cole and Kerman [9] calculated embodied CO₂ by structure and determined CO₂ emissions per floor area from traffic resulting from construction.

In some other papers, CO₂ emissions from construction were successfully reduced by getting a little creative with the materials to be used [10-12]. Lenzen and Treloar [10] compared the analytical results of inter-industrial relationships for embodied energy in construction materials, analyzed the wood and concrete designed buildings, and showed that the concrete-framed building causes higher CO₂ emissions. Gonzalez and Navarro [11] showed the possibility of reducing the CO₂ emissions up to 30% in the construction phase, through a careful selection of low environmental impact materials. Buchanan and Honey [12] compared several buildings and found that the modest change from concrete and steel to more wood construction could lead to a substantial reduction in energy requirements and carbon dioxide emissions.

Studies about embodied CO₂ are also published in volume abroad and they point out the importance of quantifying CO₂ emissions. Ramesha et al. [13] conducted a critical literature review of the life cycle energy analyses of buildings and summarized the definition of embodied energy resulting from 73 cases across 13 countries, and showed that embodied energy is 10%~20% of total energy of building life cycle.

Dixit et al. [14, 15] performed a review of literature in the realm of embodied energy, identified parameters causing variations in embodied energy data, and determined unresolved issues in existing international LCA (life cycle assessment) standards.

2. Method of Calculation

2.1 Competitive Import-Type Matrix

This paper used the producer's price-based input/output Table S publicized by the Ministry of Internal Affairs and Communications. Basic Table S has a 520×407 matrix and this was arranged into a 401×401 square matrix by consolidating column or row items containing a business name different between column and row items. Determining that the competitive import-type inverse matrix is common, such an inverse matrix is calculated, using the following equation:

$$X = \{I - (I - M)A\}^{-1} \{(I - M)F_{(D)} + F_{(E)}\} \\ m_i = M_i/C_i \quad (1)$$

where:

X : domestic output (yen/year);

$\{I - (I - M)A\}^{-1}$: Leontief competitive import-type inverse matrix (-);

I : unit matrix (-);

M : import coefficient diagonal matrix;

m_i : import coefficient (-);

M_i : import price of i product (yen/year);

C_i : domestic demand for i product (yen/year);

A : activity (input coefficient) (-);

$F_{(D)}$: domestic final demand value (yen/year);

$F_{(E)}$: import value (yen/year).

In the calculation of Eq. (1), a Leontief inverse matrix is calculated to determine the ultimate domestic output X including propagation by giving the domestic final demand value.

2.2 Determination of CO₂ Emissions Intensities

In the transaction table, the physical consumptions and prices for 134 items are given for each industrial sector. This paper prepares physical consumption intensities beforehand by dividing physical

consumption in industrial sector by the domestic output X and calculates the ultimate domestic output X including propagation for the input of one million yen's worth of domestic final demand. Assuming that physical consumptions are proportional to the domestic output calculated, final physical consumptions were determined by multiplying transaction intensities with the domestic output. The value of X recalculated by applying final demand to Eq. (1) is compared with the domestic output contained in the original table, finding six highest-order digits identical and assuring the accuracy of the inverse matrix.

Energy consumption and CO₂ emissions were also calculated, using the fossil fuel consumption shown in the transaction table. Since oil products are imported in measurable quantities, this paper used the fossil fuel consumption in each industry shown in the transaction table. But since crude oil is directly consumed for utility power and in part of the petrochemical industry, crude oil is added to oil products for these industries. Assuming that CO₂ emissions of 0.44 kg-CO₂/kg is derived from the consumption of limestone resulting from cement manufacturing, this amount was added. Energy consumption and CO₂ emissions were determined by multiplying the heating value of fossil fuel consumed within each industrial sector with the intensities of carbon dioxide (Table 1).

Table 1 Intensities of fossil fuel.

Fossil fuel	Unit	Calorific value (MJ/unit)	CO ₂ intensity (kg-CO ₂ /unit)
Coal	kg	28.9	2.506
Crude oil	L	38.2	2.613
Natural gas	m ³	40.9	2.020
Gasoline	L	34.6	2.322
Jet fuel	L	36.7	2.463
Kerosene	L	36.7	2.492
Light oil	L	38.2	2.624
A heavy oil	L	39.1	2.710
B/C heavy oil	L	41.1	2.922
Naphtha	L	34.1	2.271
LPG (liquefied petroleum gas)	kg	50.2	3.002
Coke	kg	30.1	3.251
Limestone	kg	-	0.440

3. Intensity Tables of Energy Consumption and CO₂ Emissions

3.1 Intensity Table

Table 2 shows the calculated intensities. Distribution margins are defined as wholesale + retail + railway + road + coast + port + aviation + consigned forwarding + warehouse. Among them, railway is freight excluding passengers, and road is freight excluding personal use. Input/output tables from 2005 and later contain distribution margins of those products by industry to be input into residential/wooden,

residential/non-wooden, non-residential/wooden and non-residential/non-wooden sectors, respectively. The purchaser's price-based intensities shown in Table 2 are each expressed as a weighted average value of distribution margins to be input into residential/wooden, residential/non-wooden, non-residential/wooden, and non-residential/non-wooden sectors. For products not to be input into construction such as rice, the average values of distribution margins input into all industrial sectors are used. Although the purchaser's price-based intensities differ in value depending upon the industrial

Table 2 Energy intensities and CO₂ intensities by 2005 IO table in Japan, selected from 401.

No.	Re1	Re2	Industrial sector	Energy per consumer price of million yen (MJ)	CO ₂ per consumer price of million yen (kg-CO ₂)	Quantity of material for consumer price of million yen (unit/million yen)
31	*		Crushed stones	52,030	3,640	593.1 t
32			Other non-metallic ores	5,627	400	-
79	*		Carpets and floor mats	33,507	2,364	-
80			Fabricated textiles for medical use	27,753	1,958	-
81	*		Other fabricated textile products	41,221	2,882	-
86	*		Other ready-made textile products	19,863	1,407	-
87	*	*	Timber	13,621	952	22.68 m ³
88	*	*	Plywood	22,697	1,599	7.0 m ³
89		*	Wooden chips	8,619	604	99.01 m ³
91	*		Wooden furniture and fixtures	18,484	1,319	-
92	*		Wooden fixtures	20,519	1,467	-
93	*		Metallic furniture and fixtures	27,395	2,169	-
95	*		Foreign paper and Japanese paper	73,672	5,804	-
96	*		Paperboard	70,834	5,471	12.62 t
97		*	Corrugated cardboard	50,211	3,795	16,620 m ²
98	*		Coated paper and building (construction) paper	40,538	2,976	-
102	*		Other pulp, paper and processed paper products	33,237	2,453	-
135	*		Petroleum Refinery product	12,497	882	-
137	*		Paving materials	25,269	1,813	-
138	*		Plastic products	56,893	3,971	-
142	*		Other rubber products	40,109	2,836	-
146	*		Sheet glass and safety glass	36,902	2,636	-
147	*		Glass fiber and glass fiber products	71,691	4,842	-
148	*		Other glass products	49,832	3,265	-
149	*		Cement	315,036	80,992	124.4 t
150	*		Ready mixed concrete	81,093	16,745	62.60 m ³
151	*		Cement products	43,193	5,994	-
152	*		Ceramic	54,376	3,500	-
153	*		Refractory product	42,661	3,220	-
154	*		Other construction clay products	77,937	5,751	-

(Table 2 continued)

No.	Re1	Re2	Industrial sector	Energy per consumer price of million yen (MJ)	CO ₂ per consumer price of million yen (kg-CO ₂)	Quantity of material for consumer price of million yen (unit/million yen)
155			Carbon and graphite products	62,870	4,832	-
157	*		Miscellaneous ceramic, stone and clay products	40,091	3,259	-
160			Crude steel (converters)	394,408	39,897	21.45 t
161			Crude steel (electric furnaces)	100,059	8,356	19.47 t
162	*		Hot rolled steel	189,779	18,271	13.47 t
163	*		Steel pipes and tubes	119,963	11,182	6.158 t
164	*		Cold finished steel	137,218	12,604	8.381 t
165	*		Coated steel	90,489	7,958	9.002 t
166	*		Cast and forged steel	95,785	8,400	2.374 t
167	*		Cast iron pipes and tubes	102,598	8,701	8.061 t
168			Cast and forged materials (iron)	121,695	10,616	14.54 t
169	*		Iron and steel shearing and slitting	106,916	9,838	-
170	*		Other iron or steel products	56,294	5,062	-
171			Copper	22,906	1,745	2.072 t
172	*		Lead and zinc (incorporated regenerated lead)	54,181	4,089	-
173			Aluminum (incorporated regenerated aluminum)	18,187	1,323	4.308 t
174			Other non ferrous cables	6,332	450	-
175	*	*	Electric wires and cables	22,562	1,611	0.645 conductor-t
176	*	*	Optical fiber cables	50,900	3,549	102.8 km core
177	*	*	Rolled and drawn copper and copper alloys	25,609	1,803	1.255 t
178			Rolled and drawn aluminum	22,112	1,576	1.766 t
181	*		Other non ferrous metal products	15,913	1,139	-
182	*		Metal products for construction	63,388	5,577	-
183	*		Metal products for architecture	35,353	2,878	-
184	*		Gas and oil appliances and heating and cooking apparatus	46,211	3,891	-
185	*		Bolts, nuts, rivets and springs	45,000	3,859	-
187	*		Plumber's supplies, powder metallurgy products and tools	31,310	2,515	-
188	*		Other metal products	34,987	2,855	-
189	*		Boilers	22,980	1,832	-
190	*		Turbines	25,190	2,062	-
191			Engines	29,550	2,408	-
192	*		Conveyors	28,735	2,359	-
193	*		Refrigerators and air conditioning apparatus	23,502	1,808	-
194	*		Pumps and compressors	27,127	2,238	-
215	*		Electric transformer	21,509	1,727	-
216	*		Relay switches and switch boards	22,878	1,780	-
217	*		Wiring device and supplies	15,198	1,128	-
221	*		Electric measuring instruments	5,129	369	-
222	*		Electric bulbs	24,101	1,670	-
223	*	*	Electric lighting fixtures and apparatus	24,345	1,770	284.3 p
224	*	*	Batteries	28,099	2,026	5091 p
225	*		Other electrical devices and parts	19,045	1,355	-
226	*	*	Air conditioning equipment for consumer use	21,210	1,577	11.13 p
227	*	*	Electric equipment for consumer use (ex., air conditioning)	19,780	1,498	24.80 p

(Table 2 continued)

No.	Re1	Re2	Industrial sector	Energy per consumer price of million yen (MJ)	CO ₂ per consumer price of million yen (kg-CO ₂)	Quantity of material for consumer price of million yen (unit/million yen)
228		*	Video equipment	12,556	919	25.86 p
229	*		Electric audio equipment	16,459	1,196	-
230		*	Radio and television sets	15,340	1,105	6.900 p
231	*		Wired communication equipment	16,467	1,194	-
233	*		Radio communication equipment (ex., cell phone)	20,529	1,471	-
234	*		Other communication equipment	18,928	1,366	
235		*	Personal computer	8,231	593	7.495 p
272	*		Tatami (straw matting) and straw products	13,941	970	-
275			Recycle material recovery and process	38,981	2,753	-
276		*	Residential construction (wooden)	19,921	1,707	6.318 m ²
277		*	Residential construction (non-wooden)	29,055	2,704	5.527 m ²
278		*	Non residential construction (wooden)	21,103	1,835	7.749 m ²
279		*	Non residential construction (non-wooden)	29,644	2,704	6.844 m ²
280	*		Repair of constructions	27,466	2,436	-
281			Public construction for roads	34,533	3,451	-
282			Public construction for river, drainage and others	31,684	3,333	-
283			Agricultural public construction	40,215	3,919	-
284			Railway construction	36,907	3,650	-
285			Electric power facilities construction	30,751	2,800	-
286			Telecommunication facilities construction	30,105	2,449	-
287			Other civil engineering and construction	32,585	3,199	-
288	*		Electricity supply	361,436	26,737	61.91 MWh
289			Self-power generation	297,811	19,695	116.9 MWh
290	*		Gas supply	60,992	3,864	10,910 m ³
291	*		Steam and hot water supply	216,106	13,342	161.9 GJ
292	*		Water supply	15,787	1,143	-
293			Industrial water supply	18,169	1,339	-
294	*		Sewage disposal	112,135	8,130	-
295	*		Waste disposal services (public)	44,332	3,155	-
296	*		Waste disposal services (industrial)	26,296	1,880	-
306	*		Railway transport (passengers)	27,661	2,070	-
307	*		Railway transport (freight)	52,388	3,922	-
308	*		Bus transport service	35,168	2,426	-
309	*		Hired car and taxi transport	65,172	3,982	-
310	*		Road freight transport service	690,696	47,728	-
311	*		Transport by private cars (passengers)	133,960	8,964	-
312	*		Transport by private cars (freight)	131,552	8,981	-
313			Ocean transport	693	50	-
314	*		Coastal and inland water transport	2,156,033	154,125	-
315	*		Port transport service	12,741	912	-
316	*		Air transport	65,344	4,346	-

Re1: industry sectors, which input four building sectors;

Re2: based on domestic production output by industry section and product;

*Quantity of materials for consumer price of million yen: gasoline 6.970 kL, jet fuel 16.67 kL, kerosene 14.84 kL, light oil 9.336 kL, A heavy oil 17.59 kL, B/C heavy oil 22.29 kL, naphtha 19.23 kL, LPG (liquefied petroleum gas) 14.22 kL.

sector into which such intensities are input, this paper, the target of which is buildings, prepared a purchaser's price-based table of intensities to be input into the building sector. In the case of transactions per million yen of the purchaser's price, items contained in the table are limited in number and, therefore, domestic outputs by sector and items are used in combination, thus identifying physical transaction intensities for a larger number of items.

Table 3 shows building areas and average building costs in the building sector. The 2005 input/output analysis identified CO₂ emissions per million yen from residential/wooden, residential/non-wooden, non-residential/wooden, and non-residential/non-wooden as 1,707, 2,704, 1,835 and 2,704 kg-CO₂, respectively, while the 2000 analysis had found about the same level of values of 1,725, 2,514, 1,857, and 2,540 kg-CO₂. Ready-mixed concrete discharged 16,745 kg-CO₂ per million yen in 2005, 9% more than the 15,192 kg-CO₂ in 2000. Hot-rolled steel released 18,271 kg-CO₂ in 2005, 5% more than the 17,451 kg-CO₂ in 2000. Bessemer steel emissions in 2005 were 39,897 kg-CO₂ compared with 28,550 kg-CO₂ in 2000. Emissions from electric steel

in 2005 were 8,356 kg-CO₂ compared with 19,351 kg-CO₂ in 2000, while those from crude steel as a total of Bessemer and electric steel in both years were almost the same. This is probably because the method of calculation in preparing the input/output table was changed, resulting in much lower estimated CO₂ emissions from recycled steel.

3.2 Comparison with Japanese CO₂ Emissions

Fossil fuel consumption and CO₂ emissions by industrial sector were configured per million yen of domestic output and do not include propagation. These intensities were multiplied by domestic output (one million yen) and based on the transaction, fossil fuel consumption and CO₂ emissions resulting from final demand (non-household, household) were added.

Energy consumption was 15,018,450 TJ in the endogenous sector and 3,044,729 TJ of final demand, while CO₂ emissions were 1,099,538 thousand tons-CO₂ in the endogenous sector and 191,906 thousand tons-CO₂ of final demand, totaling 1,291,444 thousand tons-CO₂. This was compared with existing materials concerning CO₂ emissions in 2005, permitting us to consider that the total CO₂ emissions

Table 3 Building floor area and construction cost.

Industry sector	Building type	Floor area (m ²)	Building cost (million yen)
Houses (wood)	Houses	60,393,873	9,565,148
	Houses with mix use	866,406	131,670
Houses (non-wooden)	SRC (steel reinforced concrete)	2,446,919	431,110
	RC (reinforced concrete)	28,761,927	5,090,743
	S (steel)	18,004,479	3,338,886
	Others	298,559	47,185
	Houses with mix use	4,035,197	779,578
Non-residential (wooden)	Factory, storage	791,609	60,018
	Office, others	3,963,556	553,617
Non-residential (non-wooden)	Factory, storage (SRC)	829,444	78,473
	Office, others (SRC)	2,986,311	699,942
	Factory, storage (RC)	1,219,598	138,911
	School (RC)	3,040,998	586,392
	Office, others (RC)	10,686,964	2,245,381
	Factory, storage (S)	21,096,424	2,113,457
	Office, school others (S)	33,083,100	4,796,792
	Concrete block, others	407,231	58,055

in this paper are reasonable since the National Institute for Environmental Studies gave 1,293,000 thousand tons-CO₂ [16] and the Greenhouse Gas Inventory Office published 1,287,000 thousand tons-CO₂ [17].

3.3 Construction-Related CO₂ Emissions

Table 4 shows CO₂ emissions in the construction/civil engineering sector and CO₂ emissions resulting from the operation of family-/business-purpose facilities. Compared with CO₂ emissions in 2000 [3], it was found that the ratio of CO₂ emissions in the construction industry to those from all of Japan decreased from 6.4% to 5.64% and, in the case of civil engineering, such a ratio decreased from 8.0% to 6.11%. The operation of family-purpose facilities witnessed an increase from 12.7% to 13.96% and the operation of business-purpose facilities saw an increase from 15.0% to 18.43%.

4. Analysis of Distribution Margins

4.1 Distribution Margins

The 2005 IO table contains distribution margins by industry on products to be input into each industrial

sector. These values are, if building sectors are targeted, of the margins occurring when final construction materials are input into building sectors and defined as purchaser margins in this paper. An appraisal of local production for local consumption requires the evaluation of distribution margins occurring among various industries resulting from production together with purchaser margins. This paper defines these distribution margins as middle margins. If ready-mixed concrete is cited as an example, margins in the mining of limestone and its carriage to a cement factory, and then on the conveyance of cement to a ready-mixed concrete plant are defined as middle margins, and margins in the carriage of ready-mixed concrete from the ready-mixed concrete plant to the construction site, as purchaser margins.

4.2 Building Industry and Average Margins for All Industries

Table 5 shows CO₂ emissions resulting from middle margins and purchaser margins in residential/wooden, residential/non-wooden, non-residential/wooden, and non-residential/non-wooden buildings.

Table 4 CO₂ emissions associated with buildings.

Industry	CO ₂ emissions (1000 × t-CO ₂)	Ratio (%)
Buildings	Wooden houses	16,552
	Non-wooden houses	26,200
	Wooden and non-residential	1,126
	Non-wooden and non-residential	28,982
	Sub total	72,860
Civil works	Road	26,380
	Others	52,537
	Sub total	78,917
Operation of houses	Coal	6
	Kerosene	42,347
	LPG	29,523
	City gas	21,911
	Electricity	86,453
	Sub total	180,239
Transport of household	96,727	7.49
Operation of non-residential buildings	238,000	18.43
Total of Japan	1,291,444	100.00

Table 5 CO₂ emissions of middle margins and purchaser margin associated with buildings.

Industry sector	Middle margins (kg-CO ₂ /million yen)	Purchaser margins (kg-CO ₂ /million yen)
Wooden house	83.8	145.1
Non-wooden house	89.3	132.1
Non-residential (wood)	79.5	124.3
Non-residential (non-wooden)	89.8	127.3
Average of all industrial sector	246.7	71.1

Fig. 1 Breakdown of CO₂ emissions of middle margins. **Fig. 2** Breakdown of CO₂ emissions of purchaser margins.

The values shown in Table 5 are of ultimate CO₂ emissions including propagation as a result of 1 million yen in input. If compared with the average values for all industries, it is found that CO₂ emissions from middle margins in building sectors are scarce at some 35% of all-industry average values while CO₂ emissions from purchaser margins are about 1.8 times,

hinting at characteristically heavy CO₂ emissions from purchaser margins in carriage from each factory to the construction site. The total of CO₂ emissions resulting from middle and purchaser margins in building sectors amounts to some 70% of emissions for all industries, finding a small ratio of CO₂ emissions to the output.

4.3 Comparison by Margin Type

Figs. 1 and 2 compare breakdowns of CO₂ emissions from middle margins and purchaser margins. CO₂ emissions resulting from middle margins in the building industry are less than the averages of all industries at 39% for wholesale, 7% for retail, and 48% for goods transported by road. If CO₂ emissions from purchaser margins are compared with the average values for all industries, wholesale is found to be twice as large as the averages for all industries, while goods transported by road was about three times larger, indicating particularly large values for roads. CO₂ emissions resulting from middle margins in materials consumed in the building industry are minor, while CO₂ emissions from purchaser margins are heavy, suggesting great effectiveness of local production for local consumption for the building industry.

5. CO₂ Emissions Resulting from Transportation

5.1 Method of Calculation

CO₂ emissions from transportation were calculated for comparison between those in the building industry and other general industries. The CO₂ emissions here were determined from values for freight traffic and passenger transportation to be input into transportation sectors. These correspond to purchaser margins in the industrial sectors in question and the transportation corresponding to middle margins is not included. Transportation sectors relating to the freights/passengers to be input into building industry sectors are all included. The calculation used a method of calculating the intensities of CO₂ emissions in

transportation sectors (kg-CO₂/million yen) beforehand for determination from the value input (1 million yen) into transportation sectors required by each construction sector.

5.2 Calculation Results

Tables 6 and 7 show the results of calculation. According to Japanese Road Policy Report [15], CO₂ emissions resulting from transportation in 2005 were 260,000 thousand tons-CO₂. In this paper, CO₂ emissions from transportation total 254,417 thousand

tons-CO₂, which is 2.1% less but determined as a roughly reasonable outcome. Calculation assuming that the gasoline and light oil consumed in the family sector be spent for transportation identifies CO₂ emissions resulting from transportation from the family sector as 96,727 thousand tons-CO₂, which accounts for 38% of transportation overall.

Table 6 shows the ratio of CO₂ emissions in each transportation sector to total CO₂ emissions occurring in each industrial sector. A comparison of all industries and the building industry finds almost no freight traffic,

Table 6 Ratio of CO₂ emissions resulting from transportation.

Sector	Ratio of CO ₂ emissions (%)				
	All industry	Building sector			
		Wooden house	Non-wooden house	Non-residential (wooden)	Non-residential (non-wooden)
Passenger train	1.090	0.149	0.093	0.180	0.108
Freight train	0.043	0.012	0.007	0.012	0.007
Bus	0.283	0.072	0.036	0.033	0.020
Taxi	0.767	0.137	0.061	0.114	0.075
Goods transport by road	3.042	3.286	1.944	2.481	2.050
Passenger car	4.569	5.550	5.084	6.078	5.422
Truck	2.508	2.744	2.442	2.838	2.571
Coastal, inland transport	0.429	0.163	0.088	0.123	0.075
Port transport	0.065	0.021	0.011	0.017	0.009
Air transport	1.546	0.080	0.040	0.076	0.046
Sub total	14.342	12.214	9.806	11.952	10.383
Total of all sector	100.000	100.000	100.000	100.000	100.000
Total CO ₂ emission (t-CO ₂)	1,099,538,000	16,552,470	26,195,010	1,126,020	28,979,860

Table 7 CO₂ emissions intensities resulting from transportation.

Sector	CO ₂ emissions (kg-CO ₂ /million yen)				
	All industry	Building sector			
		Wooden house	Non-wooden house	Non-residential (wooden)	Non-residential (non-wooden)
Passenger train	0.811	0.254	0.252	0.330	0.293
Freight train	0.032	0.020	0.020	0.021	0.019
Bus	0.211	0.122	0.097	0.060	0.055
Taxi	0.571	0.233	0.166	0.209	0.204
Goods transport by road	2.263	5.609	5.257	4.553	5.543
Passenger car	3.399	9.474	13.748	11.154	14.662
Truck	1.866	4.684	6.603	5.208	6.952
Coastal, Inland transport	0.319	0.278	0.238	0.225	0.203
Port transport	0.049	0.036	0.029	0.031	0.025
Air transport	1.150	0.136	0.108	0.140	0.124
Sub total	10.671	20.846	26.518	21.931	28.080
Total of all sector	74.399	170.700	270.400	183.500	270.400
GDP (million yen)	1,477,888,695	9,696,818	9,687,502	613,635	10,717,400

emissions in all industries are larger, although slightly, except for wooden residential buildings.

Table 7 shows CO₂ emissions corresponding to domestic outputs by industry. Compared with the averages for all industries, the values of the building industry are larger by 2 to 2.5 times in goods transported by road, 3 to 4 times in private transportation (passenger) and some 3 times in private transportation (freight), indicating that it is the industry for which CO₂ emissions from transportation are heavy for its output. Cole reported that CO₂ emissions from material handling vary widely between 0.1 kg-CO₂/m² and 1.0 kg-CO₂/m² from wooden buildings and between about 1 kg-CO₂/m² and 6 kg-CO₂/m² from RC buildings [8]. The 2005 IO Table of Japan states 158 thousand yen/m² for wooden exclusive residential dwellings, 177 thousand yen/m² for RC residential dwellings and 234 thousand yen/m² for SRC business offices. If CO₂ emissions resulting from material handling are calculated from Table 6, 1.8, 2.3 and 3.1 kg/m² are obtained, respectively. From wooden residential dwellings, Japanese CO₂ emissions are heavy, but those from RC buildings are on a similar level to Canada. In Japan, there are studies about the energy used in the transportation of materials such as steel materials and ready-mixed concrete, etc. [4-7], and studies are undertaken from the perspectives of local production for local consumption and the reduction of CO₂ emissions from transportation. Some papers [18] on CO₂ emissions associated with transportation across the building industry report that emissions from wooden detached housing account for 3.4% of the total.

In this paper, the share of wooden residential dwellings is calculated from Table 3 to give an almost identical 4.1%.

6. Conclusions

This research paper analyzed the 2005 IO table to create building industry-related intensities and, at the same time, compared the building industry with

industries at large for distribution margins and transportation. The results are summarized as follows:

(1) A competitive import-type Leontief inverse matrix was prepared and, in combination with the transaction, a method of calculation was given. Crude oil consumption was not used, but physical transactions of fossil fuel consumed in industrial sectors were used;

(2) Energy consumption and CO₂ emissions corresponding to 1 million yen's worth of production and purchase in each industry were listed in a table. Since from the 2005 IO table, distribution margins came to be shown by material to be input into the building industry, purchaser margins targeting the building industry were used;

(3) An analysis of distribution margins separately for middle and purchaser margins found that middle margins in the building industry are minor at 35% of the averages for all industries, while purchaser margins are sizable at 1.8 times, proving that it is an industry for which local production for local consumption is quite effective;

(4) CO₂ emissions resulting from transportation in the building industry were calculated and concisely characterized. Although the ratio of transportation CO₂ emissions to total CO₂ emissions in each industry finds almost no difference between general industries and the building industry, transportation CO₂ emissions per production value are 2 to 3 times heavier than those from general industries to be justified as a transportation-intensive industry. In the future, targeting actual buildings, we would like to propose and evaluate a method of reducing CO₂ emissions resulting from construction.

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