Technological Changes in Japanese Housing and Its Effects on Carbon Emissions

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Abstract

Population growth has led to the conversion of resource-related land uses, such as agricultural lands, to urban related land uses, like housing. Urban development has made life convenient and comfortable. Travel has become faster, communication has become easier. However, there are externalities that we need to face due to urban development; Externalities such as overcrowding of cities which leads to continual expansion of the city (suburbanization); traffic congestion; and the environmental quality is worsening. One aspect of urban development is the construction of residential and non-residential buildings in cities. This paper tries to study the changes of carbon emissions induced by building construction. To be able to assess the future requirements of society in terms of infrastructure facilities and its sustainability, a study on the historical changes of carbon emissions and the relationship of material requirements to emissions are necessary. The focus is on the technological evolution of Japanese building construction to be able to assess its environmental impacts and to be able to recognize the material and energy requirements of building construction that contribute to the total carbon emissions. The main contribution of the paper is the environmental evaluation of the building construction system. Moreover, carbon emissions from building construction will be one of the results from the study. The Input-Output Approach coupled with Structural Decomposition Analysis (SDA) is used to analyze the impacts of Japanese building construction to the environment. The changes in construction technology, emission structure are studied in this paper. It can be shown that these changes contribute to the fluctuations in the carbon emissions from building construction during the 15 year study period.

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1 INTRODUCTION

The recent enforcement of the Kyoto Protocol to mitigate the risk of climate change has led governments, who are signatory to the Pact, to hold in check their current emission levels and propose ways on how to limit their emissions. Infrastructure systems are necessary to the lives of human beings. However, the construction of infrastructure systems contributes to the emissions to the environment. Buildings-related CO_2 emissions account for one third of Japan's total CO_2 emissions (Ikaga, et al, 2002). Due to the immensity of CO_2 contribution from residential and non-residential construction, it is necessary to study the reasons for this huge contribution to CO_2 emissions. This paper tries to study the changes of carbon emissions induced by residential and non-residential construction for a 15 year time period. In order to reduce emissions from the construction sector, specifically the building construction sector, it is necessary to have a historical perspective on how material requirements from building construction contribute to increased or decreased emission levels. The relationship between the assessment of environment loads and the economic system is modeled through the use of the Input-Output Methodology. The conventional Input-Output model has been employed to estimate environmental loads due to the production processes of the entire economic system. Leontief (1970), Weir (1998), Gerilla, et al. (2000a) employed the static input-output model to estimate environmental loads in relation to some aspect of the economy. These studies have not considered the changing energy prices in the world, which more or less affects the values of the estimated emissions. Bullard and Herendeen (1975), Piantanakulchai, et al. (1999), resolved the problem of changing energy prices by the use of physical units for energy sectors.

The comparison of changes in structure can be modeled through the structural decomposition analysis (SDA). It represents a way of distinguishing major sources of change in an economy. Several researches had been made in this area using the SDA methodology like Rose & Chen (1991); Fujimagari (1989); Skolka (1989); Weir (1998) and others. Dietzenbacher and Los (1998), moreover, showed a detailed sensitivity analysis of the decomposition. Gerilla, et al. (2000b, 2001) studied the effects of historical and technological changes in the road construction industry which made use of the rectangular input-output method.

The present paper shows a connection between the internal decomposition, wherein the direct and indirect dependencies in the economy are explicitly exhibited, and the external decomposition known as SDA is also done. The sources of changes in carbon emission intensities induced by housing construction in Japan are studied from 1980 to 1995. A sensitivity analysis of changes in the input coefficients of the final demand converter and that of the total carbon emission intensity is also presented. The paper is organized as follows: the following section discusses the framework of the study. The decomposition of structural changes is done in Section 2. Following that is the empirical application of the model using the IO tables of Japan. Concluding comments closes the paper in Section 4.

2 FRAMEWORK OF THE STUDY

The carbon emission model that is formulated in this paper incorporates the hierarchical relationship of the economic system. The methodology for modeling carbon emissions is shown in Figure 3.1. The basic input-output matrix is combined with the primary energy sectors to get a hybrid input-output matrix. The hybrid commodity by commodity direct requirements matrix is then calculated. Using the hierarchical decomposition technique, the commodity production function is modeled. To check the veracity of the modeled production function, it is compared with the hybrid production function from the data. If the two production functions are equal then the next step is the estimation of the final demand for every building construction category called the final demand converter. The carbon intensity model is formulated after all the above processes are done. A more detailed explanation of the process is presented in the following sections.

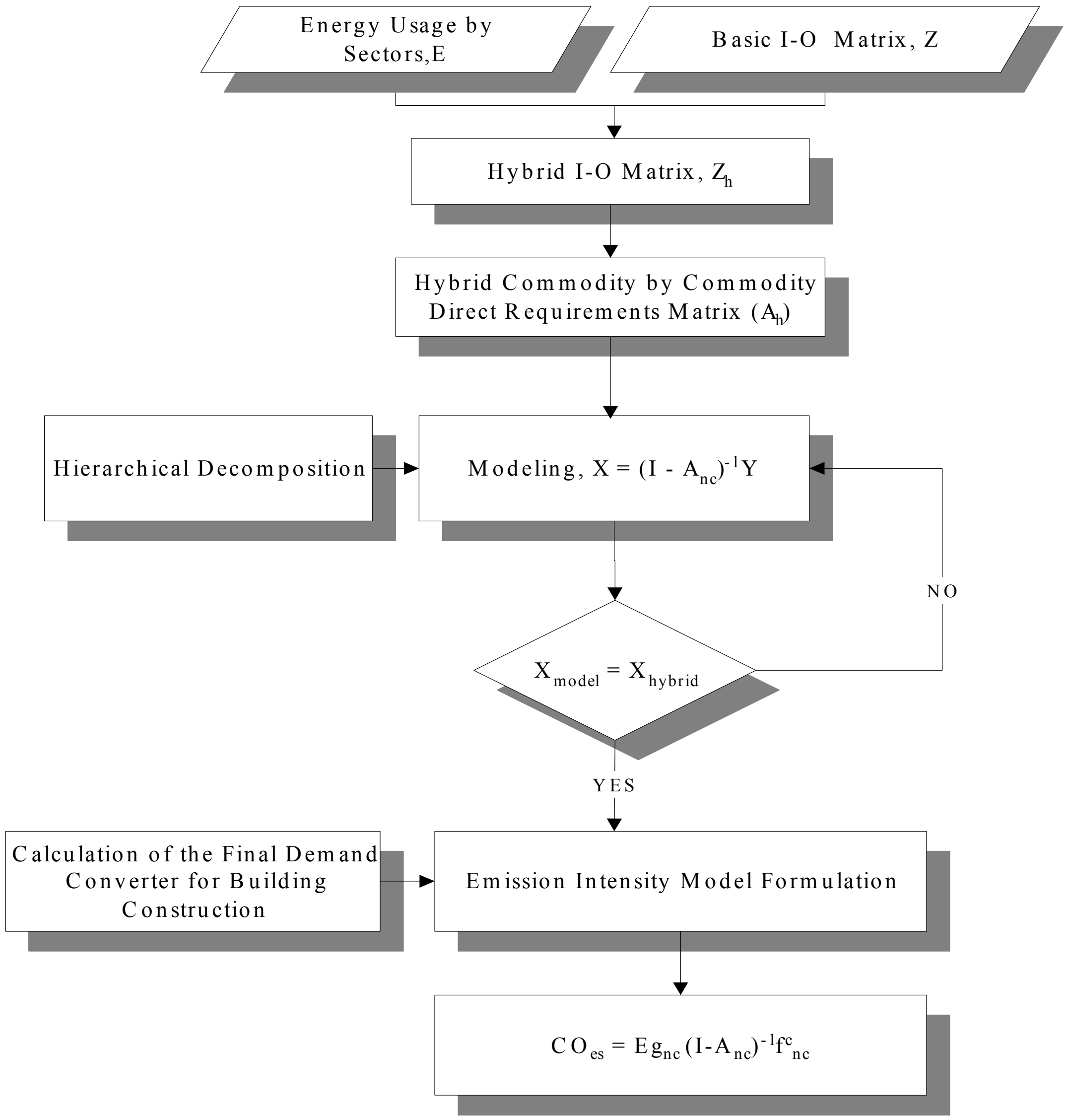

Figure 1. Flowchart of the carbon emission modeling

2.1 Hierarchical Decomposition

The economy in this model is subdivided into 3 subsystems namely: the primary energy sectors (es), the non-construction sector (nc) and the construction sector, (cs). The different interactions and hierarchy between these subsystems are presented in this section. The comparison of the emission structure among the primary energy sector, non-construction sector and construction sector can be explained using the decomposition of the matrices. The subdivision of block matrices A_h are shown in the figures below.

$$\begin{array}{c} \\ es \\ nc \\ cs \end{array}\underbrace{\begin{array}{c} \begin{array}{ccc} es & nc & cs \end{array} \\ \left[\begin{array}{c|c|c} A_{11} & A_{12} & A_{13} \\ \hline A_{21} & A_{22} & A_{23} \\ \hline A_{31} & A_{32} & A_{33} \end{array}\right] \end{array}}_{A_h} = \begin{array}{c} es \\ nc \\ cs \end{array}\underbrace{\left[\begin{array}{c|c|c} A_{11} & A_{12} & A_{13} \\ \hline A_{21} & O & O \\ \hline A_{31} & O & O \end{array}\right]}_{A_{es}} + \begin{array}{c} es \\ nc \\ cs \end{array}\underbrace{\left[\begin{array}{c|c|c} O & O & O \\ \hline O & A_{22} & A_{23} \\ \hline O & A_{32} & O \end{array}\right]}_{A_{nc}} + \begin{array}{c} es \\ nc \\ cs \end{array}\underbrace{\left[\begin{array}{c|c|c} O & O & O \\ \hline O & O & O \\ \hline O & O & A_{33} \end{array}\right]}_{Acs} \quad (1)$$

where:

A_{11} = input coefficient sub-matrix of primary energy sectors required by the output of primary energy sectors (ton-C/ton-C);
A_{12} = input coefficient sub-matrix of primary energy sectors required by the output of non-construction sectors (ton-C/MY);
A_{13} = input coefficient sub-matrix of primary energy sectors required by the output of construction sectors (ton-C/MY);
A_{21} = input coefficient sub-matrix of non-construction sectors required by the output of primary energy sectors (MY/ton-C);
A_{22} = input coefficient sub-matrix of non-construction sectors required by the output of non-construction sectors (MY/MY);
A_{23} = input coefficient sub-matrix of non-construction sectors required by the output of construction sectors (MY/MY);
A_{31} = input coefficient sub-matrix of construction sectors required by the output of primary energy sectors (MY/ton-C);
A_{32} = input coefficient sub-matrix of construction sectors required by the output of non-construction sectors (MY/MY);
A_{33} = input coefficient sub-matrix of construction sectors required by the output of construction sectors (MY/MY);

The subdivision of the matrices is also done to be able show the hierarchy of forward linkages, backward linkages versus the isolated sub-system which in this case is the construction industry. The production function for the sectors was decomposed according to the structure of the A_h matrices in (1). This decomposition shows the strengths of the linkages between the non-construction sector, nc, the construction sector, cs and the primary energy, es, which induces the amount of emissions from the construction sector. It also aids in the understanding of the relationships in the large economic system. The decomposed production function is shown:

$$X = (I + L_o A_{es})(I + L_1 A_{cs})(I - A_{nc})^{-1} f \qquad (2)$$

where:

$Lo = (I-A)^{-1}$ $\qquad$ $L_1 = (I-A_a)^{-1}$
$A_a = A_{nc} + A_{cs}$

From equation (2), we have E_g as the matrix of total carbon emission coefficient induced by the non-construction sector for the production of final demand. This represents the emission structure of primary energy sectors. It represents the interconnections of the primary energy sector, the non-construction sector and the construction sector, which contributes to carbon emissions.

$$E_g = \left(I + L_o A_{es}\right)\left(I + L_1 A_{cs}\right) \quad (3)$$

Equation (3) can be presented in matrix form as follow:

$$E_g = \left[\begin{array}{c:c:c} E_{g11} & E_{g12} & E_{g13} \\ \hdashline E_{g21} & E_{g22} & E_{g23} \\ \hdashline E_{g31} & E_{g32} & E_{g33} \end{array}\right] \quad (4)$$

where:
E_{g11} = primary energy output sub matrix of primary energy sectors induced by the final demand of the carbon-producing sector;
E_{g12} = primary energy output sub matrix of primary energy sectors induced by the final demand of the non-construction sector;
E_{g13} = primary energy industry output sub matrix of primary energy sectors induced by the final demand of the construction sector;
E_{g21} = non-construction output sub matrix of primary energy sectors induced by the final demand of the carbon-producing sector;
E_{g22} = non-construction output sub matrix of primary energy sectors induced by the final demand of the non-construction sector;
E_{g23} = non-construction output sub matrix of primary energy sectors induced by the final demand of the construction sector;
E_{g31} = construction output sub matrix of primary energy sectors induced by the final demand of the carbon-producing sector;
E_{g32} = construction output sub matrix of primary energy sectors induced by the final demand of the non-construction sector;
E_{g33} = construction output sub matrix of primary energy sectors induced by the final demand of the construction sector;

The carbon emission coefficient vector of primary energy sectors is given in the matrix below:

$$E_{ge} = \left[\begin{array}{c:c:c} E_{g11} & E_{g12} & E_{g13} \end{array}\right] \quad (5)$$

E_{ge} is defined as the direct and indirect emission output acquired as a result of the production processes of the primary energy sectors, non-construction and the construction sectors. To be able to get the direct and indirect emission output discharged in the processes of the non-construction industry, we can decompose equation (5) to equation (6) as shown below:

$$E_{gnc} = \left[\begin{array}{c:c:c} O & E_{g12} & O \end{array}\right] \quad (6)$$

2.2 Final Demand

The building construction commodity used as final demand in this paper is composed of all buildings related construction such as wooden building construction, steel construction, reinforced concrete construction, etc. The final demand used for the production of a building construction commodity is a final demand converter. A final demand converter is used because no detailed construction category is given in the basic I-O table. This converter is taken from the input transactions of the construction sector. The final demand converter, f_i^c, is defined as the input coefficient for construction as shown in equation 7.

$$f_i^c = \frac{p_i^c}{\sum_i P_i^c} \tag{7}$$

where:
p_i^c = input coefficient from the industrial sector i for the building construction category c;
P_i^c = cost of inputs from the industrial sector i for the construction category c

The final demand for a building construction commodity can be converted into the hybrid system as given in the vector:

$$f_i^c = \left[f_{es}^c \,\vdots\, f_{nc}^c \,\vdots\, f_{cs}^c \right]^t \tag{8}$$

where:

f_i^c = final demand converter for every construction commodity c;
f^c_{es} = Final demand of the primary energy industry requirements of a construction commodity;
f^c_{nc} = Final demand of the non-construction industry requirements of a construction commodity;
f^c_{cs} = Final demand of the construction industry requirements of a construction commodity;

Note that the symbol (^{t}) means the transpose of the vector. The final demand converter used is the non-construction-input requirements of a building construction commodity. The final demand converter can also be subdivided into each building construction category. The equation below shows the final demand converter used for every construction category.

$$f_{nc}^c = f_{nc}^{src} + f_{nc}^{rc} + f_{nc}^{s} + f_{nc}^{w} + \ldots \tag{9}$$

The carbon emission function can be formulated from equations (6), (10) and (13); the total carbon emission intensity from the primary energy sectors induced by the non-construction sector for the production of a construction commodity is given by:

$$CO_{es} = E_{gnc} * (I - A_{nc})^{-1} * f_{nc}^c \tag{10}$$

where:

CO_{es} = Total carbon emission intensity of a construction commodity induced by the processes in the non-construction sector for the production of a construction commodity (ton-C/MY);
E_{gnc}= Carbon emission coefficient vector of primary energy sector;
$(I - A_{nc})^{-1}$= Total requirements matrix induced by the non-construction sector;
f^c_{nc} = Final demand of the non-construction requirements of a construction commodity;

2.3 Structural Decomposition Analyses

The sources of changes in carbon emission intensity are studied using SDA. The total change in carbon emissions intensities is decomposed into effects caused by the changes in the emission structure of primary energy sectors, E_{gnc}, changes in non-construction technology,

$(I - A_{nc})^{-1}$ as well as changes in the construction technology of the building construction. Using equation (10), we can carry out its decomposition over time by

$$\Delta CO_{es} = \left\{ E_{gnc} \left(I - A_{nc} \right)^{-1} f_{nc}^{c} \right\}_1 - \left\{ E_{gnc} \left(I - A_{nc} \right)^{-1} f_{nc}^{c} \right\}_0 \tag{11}$$

The subscripts 1 and 0 denote the future year t1 and base year t0, respectively. If we let $L_{nc} = (I - A_{nc})^{-1}$, we have:

$$\Delta CO_{es} = E_{gnc1} L_{nc1} f_{nc1}^{c} - E_{gnc0} L_{nc0} f_{nc0}^{c} \tag{12}$$

Equation (12) can be transformed into six different types of decomposition forms, which are shown in equation (13).

$$\begin{aligned} \Delta CO_{es} &= \Delta E_{gnc} L_{nc1} f_{nc1}^{c} + E_{gnc0} \Delta L_{nc} f_{nc1}^{c} + E_{gnc0} L_{nc0} \Delta f_{nc}^{c} \\ &= \Delta E_{gnc} L_{nc0} f_{nc0}^{c} + E_{gnc1} \Delta L_{nc} f_{nc0}^{c} + E_{gnc1} L_{nc1} \Delta f_{nc}^{c} \\ &= \Delta E_{gnc} L_{nc1} f_{nc0}^{c} + E_{gnc0} \Delta L_{nc} f_{nc0}^{c} + E_{gnc1} L_{nc1} \Delta f_{nc}^{c} \\ &= \Delta E_{gnc} L_{nc0} f_{nc0}^{c} + E_{gnc1} \Delta L_{nc} f_{nc1}^{c} + E_{gnc1} L_{nc0} \Delta f_{nc}^{c} \\ &= \Delta E_{gnc} L_{nc0} f_{nc1}^{c} + E_{gnc1} \Delta L_{nc} f_{nc1}^{c} + E_{gnc0} L_{nc0} \Delta f_{nc}^{c} \\ &= \Delta E_{gnc} L_{nc1} f_{nc1}^{c} + E_{gnc0} \Delta L_{nc} f_{nc0}^{c} + E_{gnc0} L_{nc1} \Delta f_{nc}^{c} \end{aligned} \tag{13}$$

ΔE_{gnc} represents the changes in the emission structure of the primary energy sector, while ΔL_{nc} represents the changes in the non-construction technology and Δf_{nc}^{c} denotes the final demand changes of the non-construction requirements of a building construction commodity. Dietzenbacher and Los (1998) suggested that the average of polar decompositions be computed for cases with more than two determinants. So the average effects of the determinants are computed. The average effects of the emission structure changes of the primary energy sectors, ΔE_{gnc} can be calculated by the formula:

$$(1/6) \cdot \left[2 \cdot \left(\Delta E_{gnc} L_{ncl} f_{ncl}^{c} \right) + 2 \cdot \left(\Delta E_{gnc} L_{nc0} f_{nc0}^{c} \right) + \Delta E_{gnc} L_{ncl} f_{nc0}^{c} + \Delta E_{gnc} L_{nc0} f_{ncl}^{c}) \right] \tag{14}$$

The average effects of the changes in non-construction technology are manifested in equation (15).

$$(1/6) \cdot \left[2 \cdot \left(E_{gnc0} \Delta L_{nc} f_{nc0}^{c} \right) + 2 \cdot \left(E_{gnc1} \Delta L_{nc} f_{nc1}^{c} \right) + E_{gnc0} \Delta L_{nc} f_{nc1}^{c} + E_{gnc1} \Delta L_{nc} f_{nc0}^{c} \right] \tag{15}$$

Equation (16) estimates the average effects of changes in construction technology.

$$(1/6) \cdot \left\{ 2 \left(E_{gnc0} L_{nc0} \Delta f_{nc}^{c} \right) + 2 \left(E_{gnc1} L_{nc1} \Delta f_{nc}^{c} \right) + E_{gnc1} L_{nc0} \Delta f_{nc}^{c} + E_{gnc0} L_{nc1} \Delta f_{nc}^{c} \right\} \tag{16}$$

It should be noted that the final demand used in the study is a final demand converter, which consists of the input coefficients of each building construction category, in effect, Δf_{nc}^{c} can be called the changes in the construction technology for each building construction category.

3 RESULTS

The result of the calculations and analysis is presented in this section. The decomposition equations presented in section 3.3 are applied to the analysis of the changes in the carbon emission intensities for building construction from 1980 to 1995. These periods were chosen to be able to trace the historical changes of carbon emissions in Japan induced by housing and non-housing construction. The application of the decomposition equations are done for the residential and non-residential building construction and its commodities.

3.1 Basic Data

The data used in the study were the basic commodity by commodity input-output tables from the Management and Coordination Agency; the energy usage by sectors based on the input-output analysis and the input tables for construction work from the Ministry of Construction, Japan. All the above mentioned data were collected for the years 1980, 1985, 1990 and 1995.

The sector classification in the input-output tables for different years do not correspond to each other therefore all the tables were aggregated into a 60 x 60 matrix for each analysis year. The aggregation was done to be able to make all the sectors uniform and manageable. Moreover, all monetary terms were converted to 1985 prices to facilitate comparison and to exclude price components from the analysis of structural change. The sectors were rearranged according to the primary energy sectors, non-construction sector and the construction sector. There are 7 sectors in the primary energy sector (es) which is composed of coal mining, crude petroleum and natural gas, Limestone, petroleum refinery products, coal products, electricity and power generation and gas supply and steam. Two sectors are from the construction industry (cs) namely: the residential and non-residential construction sector and civil engineering construction sector, and lastly, the other 51 sectors are the non-construction (nc) sectors.

The building construction category was divided into residential construction and non-residential construction. Further subdivision of these two categories was made into wooden and non-wooden construction. Non-wooden construction was again divided into steel construction, steel reinforced concrete construction, etc.

3.2 Carbon Emission Survey

Figure 2 shows the carbon emission intensity for residential and non residential construction for the 15 year study period. These intensities are based on 1985 constant prices. The trend of carbon emissions can also be seen from 1980 to 1995. During the 15 year period, the carbon emission intensity increased by about 65% for residential housing construction, while there was only a 26% increase in emissions for non-residential construction during the same period. The emission level was at its lowest from 1985 to 1990, for both residential and non-residential housing construction. There was a 27% and a 26% decrease in emissions during this period for residential and non-residential construction, respectively. The decrease in emission intensities from 1980 to 1985 was not so drastic for residential construction (only 6%) compared to the 22% decrease for non-residential construction. The trend in emissions is similar for both residential and non-residential construction. It is noted, however, that emissions from non-residential building construction are larger than those of residential construction. The lowest emission intensity for the 15 year period was in 1990 with a 620 kg-C/MY intensity for residential construction while a 687 kg-C/MY intensity for non-residential construction. The emission reduction by the Kyoto Protocol relative to 1990 levels is proper because of the lowest emission intensity during the period. However, it will be difficult to abide by the guideline because the carbon emission intensity increased in 1995 with an increase of as much as 145% for residential construction and about 123% for non-residential construction

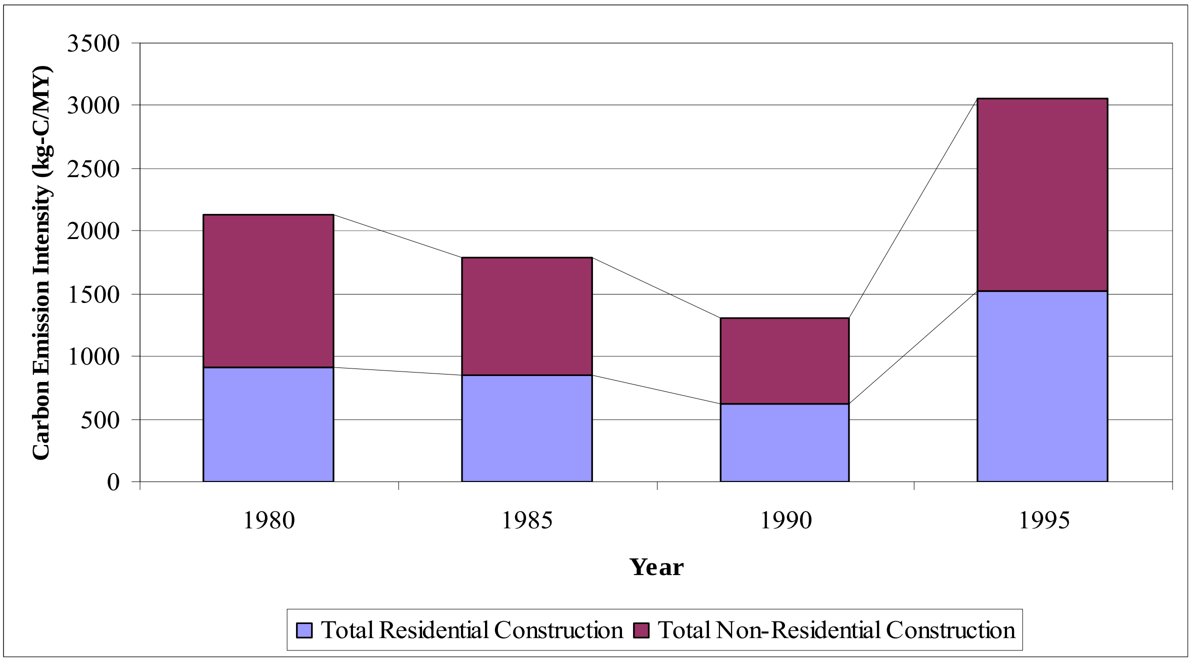

Figure 2 Carbon Emission Intensities for Residential and Non-residential Construction for a 15 year period

Figure 3 shows the carbon emission intensities according to the contribution of primary energy. It can be seen that Petroleum Refinery Products dominate the other primary energy sectors in the contribution to carbon emissions. This dominance is reflected for both residential and non-residential construction. Usage of petroleum refinery products was about 35% compared to other primary energy sectors in 1995. Even though there was dominance in this sector, we can see that the usage of petroleum refinery products gradually decreased from 23% in 1980-1985 to 36% from 1985-1990. The gradual reduction in carbon emission intensity from this sector was, however, nullified because of an increase of carbon emission intensity by 200% during 1990-1995. The second largest emitter of carbon emissions is the usage of coal products in the construction process. On average, the contribution of the usage of coal products for residential and non-residential construction to carbon emissions was about 29%. For the 15 year period, coal mining and gas supply sectors contributed to the largest increase in carbon emission.

From the carbon emission structure of residential and non residential construction, we move into the non-construction sectors, which contributed to the fluctuation of emission intensities during the 15 year period. Figure 4 shows the material/services contribution to the building construction emission intensity. The selected non-construction industries are cement, pig iron and crude steel, transportation, and steels. The selection was done based on the ranking of the emission intensities induced by the non-construction industry. The graph shows that for each analysis period, pig iron/crude steel contributed to the largest amount of carbon emissions.

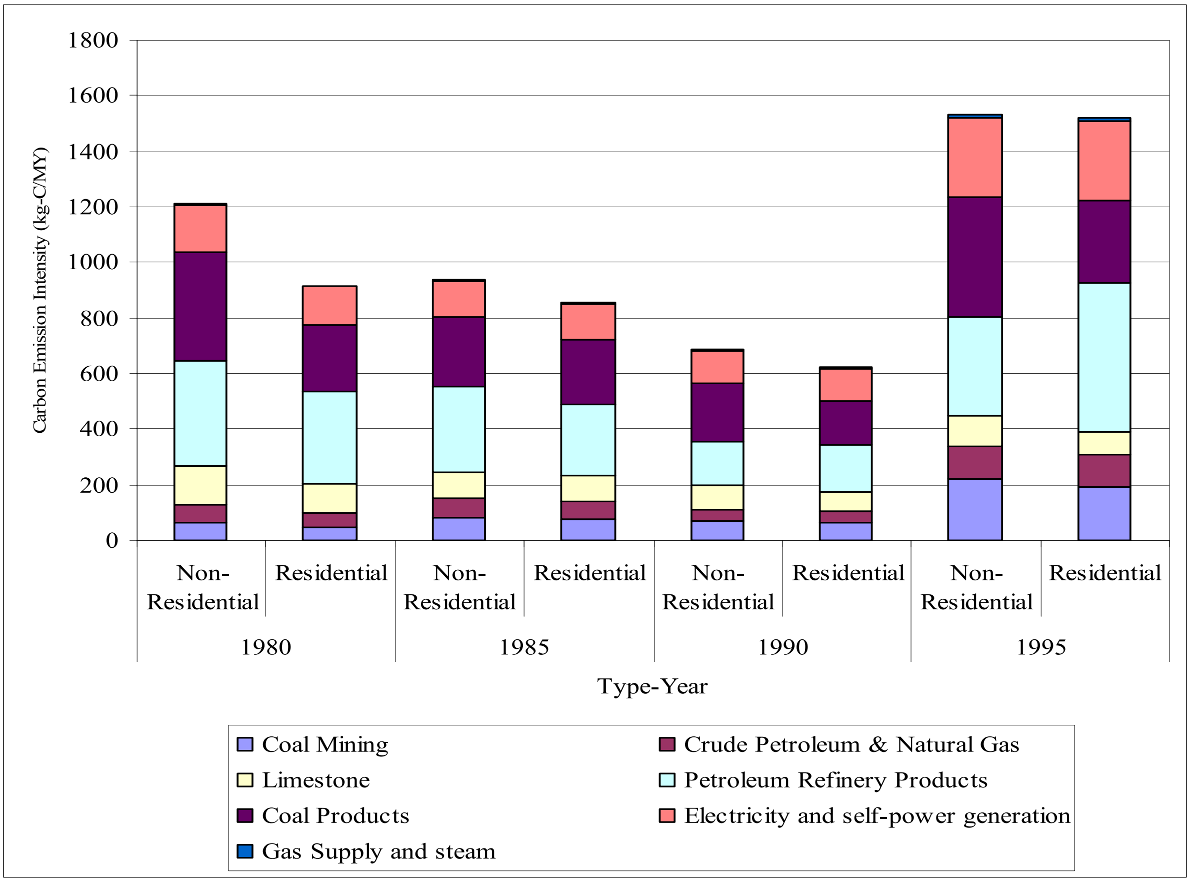

Figure 3 Carbon emission intensities according to the contribution of primary energy

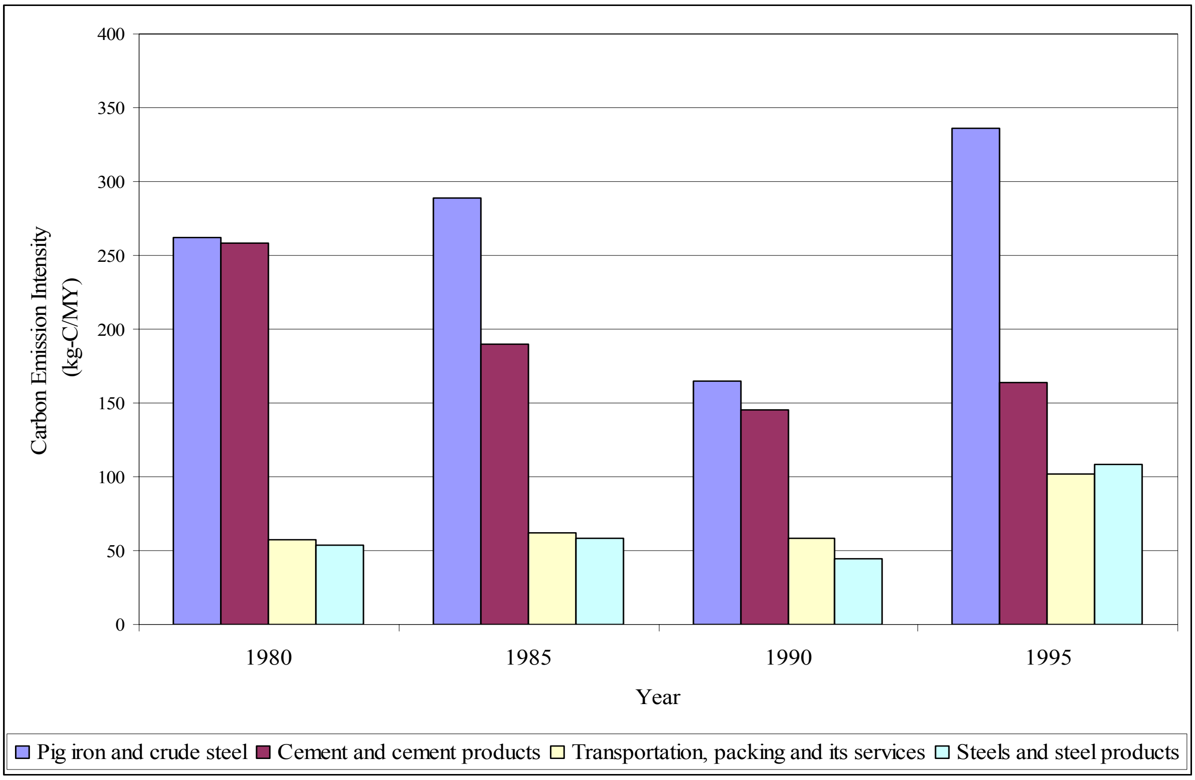

Figure 4. Material/services contribution to the building construction emission intensity

The second highest material contributor to carbon emission intensity is the cement industry. For the 15 year period, we see that emissions from cement and cement products significantly decreased by about 36% while emission intensities for transportation services increased by about 77%. The greatest contributor to the increase in emission intensity for the 15 year period is steels and steel products with a 103% increase. The reasons for the changes in carbon emissions are discussed in the next section.

3.3 Results from the Decomposition Analysis

The results of the decomposition analysis of the structural changes in carbon emission intensities induced by building construction are presented in this section. Table 1 and Table 2 present the results of the decomposition equations used in the section 2. Table 1 shows the decomposition analysis for residential construction while Table 2 shows the results of the decomposition analysis from non-residential construction. The results from the decomposition for both residential and non-residential construction show the same trend.

Table 1 Decomposition Analysis for Residential Construction (kg-C/MY)

Period	ΔEg_{nc}	ΔA_{nc}	Δf_{nc}	ΔCO_{es}
1980-1985	-156.76	-32.91	127.53	-62.14
1985-1990	-70.96	-87.83	-74.89	-233.68
1990-1995	595.85	-129.75	433.29	899.39
1980-1995	401.31	-426.36	628.62	603.57

Table 2 Decomposition Analysis for Non-Residential Construction (kg-C/MY)

Period	ΔEg_{nc}	ΔA_{nc}	Δf_{nc}	ΔCO_{es}
1980-1985	-180.40	-64.26	-30.07	-274.73
1985-1990	-96.16	-109.19	-43.89	-249.24
1990-1995	390.65	-106.84	561.83	845.64
1980-1995	63.18	-467.34	725.83	321.67

The total changes in carbon emissions (ΔCO_{es}) for a certain time interval can be decomposed into changes in emission structure, ΔEg_{nc}, changes in non-construction technology, ΔA_{nc}, and changes in the input coefficients of building construction, Δf_{nc}. Emission structure changes are sets of reciprocal action of the subsystems that induce carbon emissions. Changes in input coefficients are basically changes in the building construction technology.

The increase in carbon emissions from 1980–1995 is a result of the increase in the input coefficients of the building construction; this is true for both residential and non residential construction. Another reason for the increase is the increase in the emission structure; this might mean an increase in the building construction industry's usage in carbon intensive primary energy sources. It is important to note that a negative effect in carbon emission intensity resulted from the changes in non-construction technology. This negative effect is explained as improvement in the overall non-construction technology used for construction during this period.

The period in 1980-1985 indicates that the decrease in emission is mainly due to the change in the primary energy sectors' emission structure. This reveals that dependence on energy intensive industries has waned and shifted to less energy intensive industries, which contributed to the decrease in carbon emissions. Another reason is the improvement of non-construction technology during this period.

The biggest dip in the emission change occurred during 1985-1990; this is the result of improvement in emission structure, non-construction technology and construction technology. This reflects increased industrial efficiency and productivity in construction design and methods. The slowing down of the economy due to the bursting of the bubble economy during this time maybe another reason for the change in the input coefficients of building construction.

For 1990-1995, a drastic increase in carbon emission intensity occurred as compared to the previous period. This is due to the increase in final demand as well as increased change in the emission structure although the non-construction technology improved in this period it was offset by increase in other variables.

We saw that the biggest decrease in carbon emission intensity occurred during 1985-1990. We will look into the material inputs to residential construction which contributed to the decrease in intensities. Table 3 shows the top 5 intermediate input requirement of building construction which contributed to the major decrease in carbon intensity for 1985-1990. The top 5 material inputs to residential construction that contributed to the decrease in carbon emissions for 1985-1990 are: metal products for construction, cement and cement products, steels, timber and wooden products and organic and inorganic chemicals. The table shows that metal product for construction contributed to a marked decrease in carbon emission intensity for the period. The carbon emission intensity embedded in the metal products roughly composes about 45% of the total change in carbon emission intensity. This is due to the improvement in the emission structure, non-construction technology and construction technology. For steels, however, we see an improvement in the emission structure and manufacturing technology but there was an increase in the input coefficient for construction which is an increase in the final demand for steel.

Table 3 Effects that contributed to a major decrease in carbon intensity from residential construction for 1985-1990 (kg-C/MY)

Period	Industry	ΔE_{gnc}	ΔA_{nc}	Δf_{nc}	Total
1985-1990	Metal products for construction	-25.929	-38.244	-40.13	-104.301
	Cement and cement products	-14.014	-2.752	-28.183	-44.95
	Steels and steel products	-24.288	-33.195	17.866	-39.616
	Timber and wooden products	6.522	-6.183	-17.792	-17.455
	Organic and inorganic chemicals	-7.143	0.268	-4.047	-10.923

Table 4 shows the effects which contributed to the major increase in carbon emission intensity from 1990-1995. It can be seen that timber and timber products, metal products for construction, furniture and fixtures, cement and transportation were the top 5 material/service inputs which led to the increase in carbon emission. We can see that for the 5 material inputs, their manufacturing technology improved as seen in the negative effects while both emission structure and construction coefficient inputs had positive effects.

Table 4 Effects that contributed to a major increase in carbon intensity from residential construction for 1990-1995 (kg-C/MY)

Period	Industry	ΔE_{gnc}	ΔA_{nc}	Δf_{nc}	Total
1990-1995	Timber and wooden products	253.781	-63.845	173.116	363.049
	Metal products for construction	100.967	-28.702	240.891	313.157
	Furniture and fixtures	51.959	-2.628	54.09	103.421
	Cement and cement products	-52.417	-6.857	155.379	96.103
	Transportation, packing and its services	9.569	-1.334	8.929	17.165

3.4 Results from the Sensitivity Analysis

A sensitivity analysis of the carbon emission intensity based on the input coefficient of building construction was done to be able to know how much change in carbon emissions will occur for a change in the construction input coefficients. The construction input coefficients chosen are material inputs which contributed in the major increase in carbon emissions for 1990-1995 as seen in Table 4. Figure 5 shows the result of the sensitivity analysis. The abscissa shows the construction input coefficient while the ordinate shows the carbon emission intensity. The values for the x-axis show a decrease or increase from the current input coefficient (1). A value of 1.1 in x shows a 10 percent increase in the input coefficient of a certain material input. The sensitivity was done such that when an input $f_{nc}i$ is altered, the other input coefficients are also changed according to the scale of its contribution to the sum of the input coefficients.

As seen in Figure 5, carbon emission intensity embedded in timber and its products is highly sensitive to small changes in the input coefficient of timber and its products. We see that if we reduce the input coefficient of timber by 50% the change in the total carbon emission intensity will be reduced by about 2.5%. Similarly, carbon emission from cement and cement products are also sensitive. An increase in the input coefficient of cement and cement products by 50% will generate an increase in carbon emission intensity by 1.6%. The carbon emission intensity of the other material/services input like metal products for construction and transportation are not so sensitive to the changes in its input coefficient.

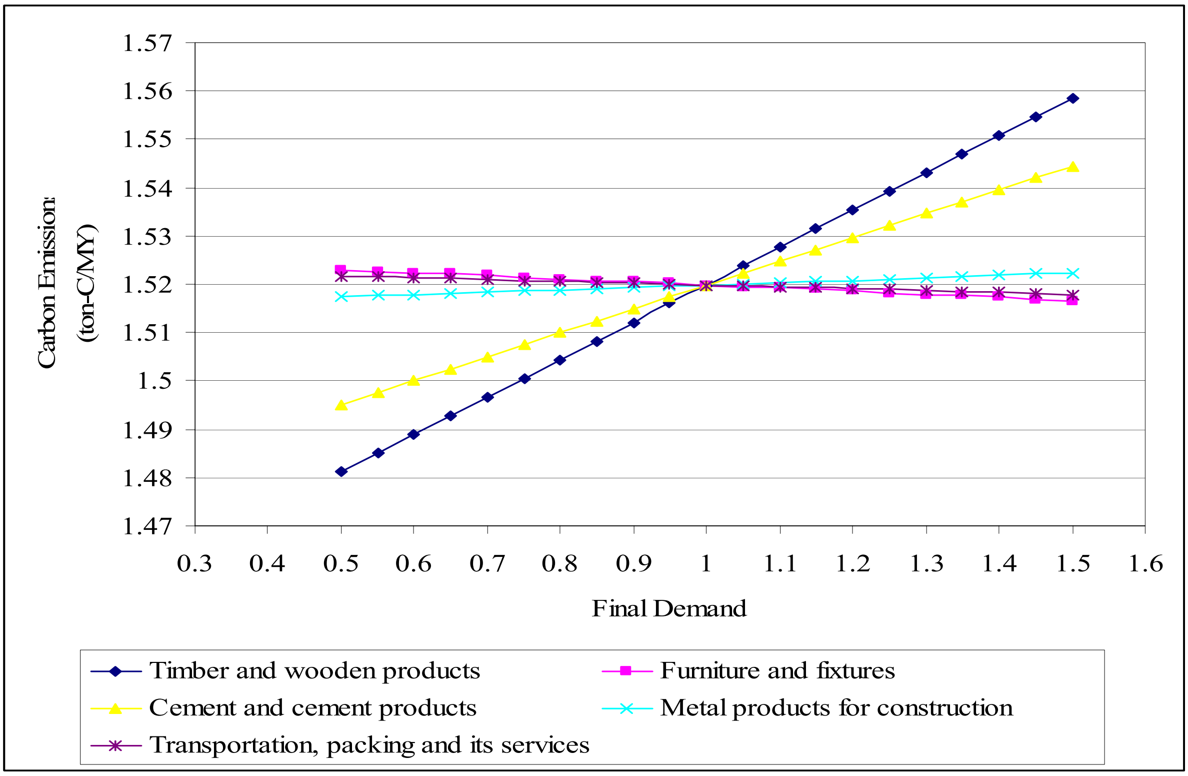

Figure 5. Sensitivity analysis done between the input coefficients of residential construction and carbon emission intensity

Knowing the sensitivity of the carbon emissions to changes in the material/services input coefficients is important in determining which sector should be focused on when trying to reduce the carbon emissions from building construction. Design of buildings using different types of materials which are not so carbon intensive/sensitive can be another way of trimming down carbon emissions.

4 CONCLUDING REMARKS

The structural decomposition analysis (SDA) developed using the hybrid framework has shown the important sources of change in carbon emissions induced by building construction. The changes in emission structure, non-construction input structure, and building construction technology has been clearly defined in the model. Another feature of the study is the differentiation between residential and non-residential building construction, which affect the carbon emission intensities.

The 15 year analysis period shows that carbon emission intensity significantly increased for both residential and non-residential construction. The reasons for the increase were the increase in the input coefficients of the building construction; this is true for both residential and non residential construction. Another reason for the increase is the increase in the emission structure; this means an increase in the building construction industry's usage in carbon intensive primary energy sources, mainly petroleum refinery products. It is worthy to note that during the 15 year period, material and manufacturing technology for building construction improved extensively. The greatest improvement in residential and non-residential construction technology can be seen in the period of 1985-1990 where the greatest decrease in emissions can be seen. This improvement led to a decrease in emission levels. This reflects increased industrial efficiency and productivity in construction design and methods. The slowing down of the economy due to the bursting of the bubble economy during this time maybe another reason for the change in the input coefficients of housing and non-housing construction. The shifts in usage of primary energy also led to a decrease in carbon emission levels. It can be seen that timber and timber products, metal products for construction, furniture and fixtures, cement and transportation were the top 5 material/service inputs to housing construction which led to the increase in carbon emission. We can see that for the 5 material inputs, their manufacturing technology improved as seen in the negative effects while both emission structure and construction coefficient inputs had positive effects.

The minute and large changes in the usage of some materials, like timber and it products and cement and its products, lead to a drastic change in carbon emissions compared to other material/services inputs. Knowing the sensitivity of the carbon emissions to changes in the material/services input coefficients is important in determining which sector should be focused on when trying to reduce the carbon emissions from housing construction. Design of houses using different types of materials which are not so carbon intensive/sensitive can be another way of trimming down carbon emissions from this sector.

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