Estimates of Embodied Carbon Emission Intensities of Building Construction in Japan by Using Input and Output Table

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1. Introduction

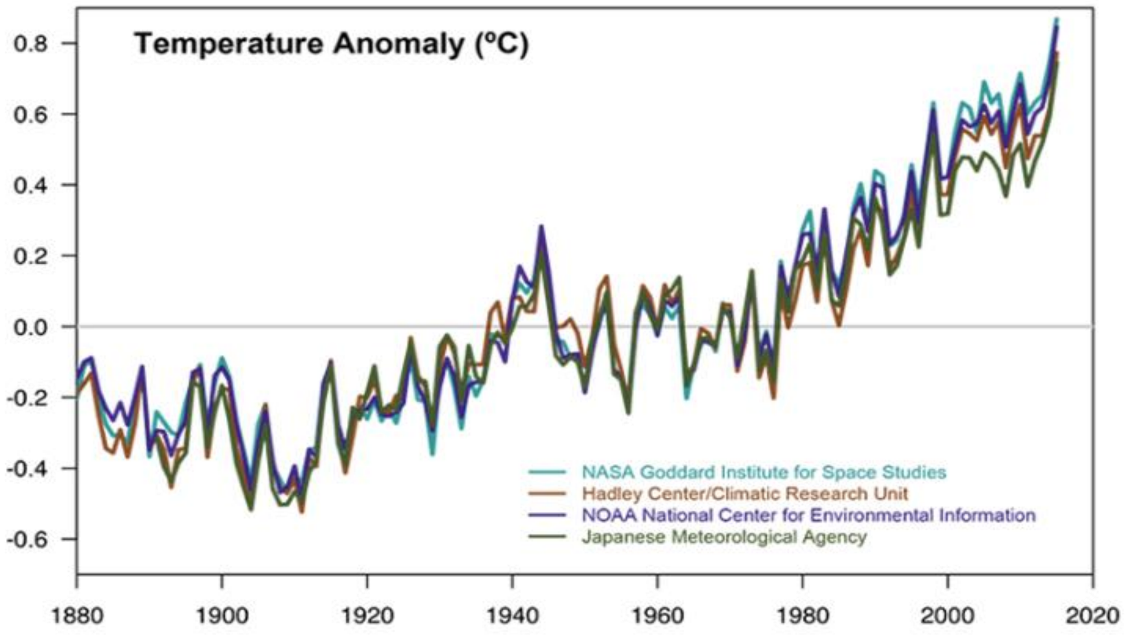
2. Method and Data

3. Results and Discussions

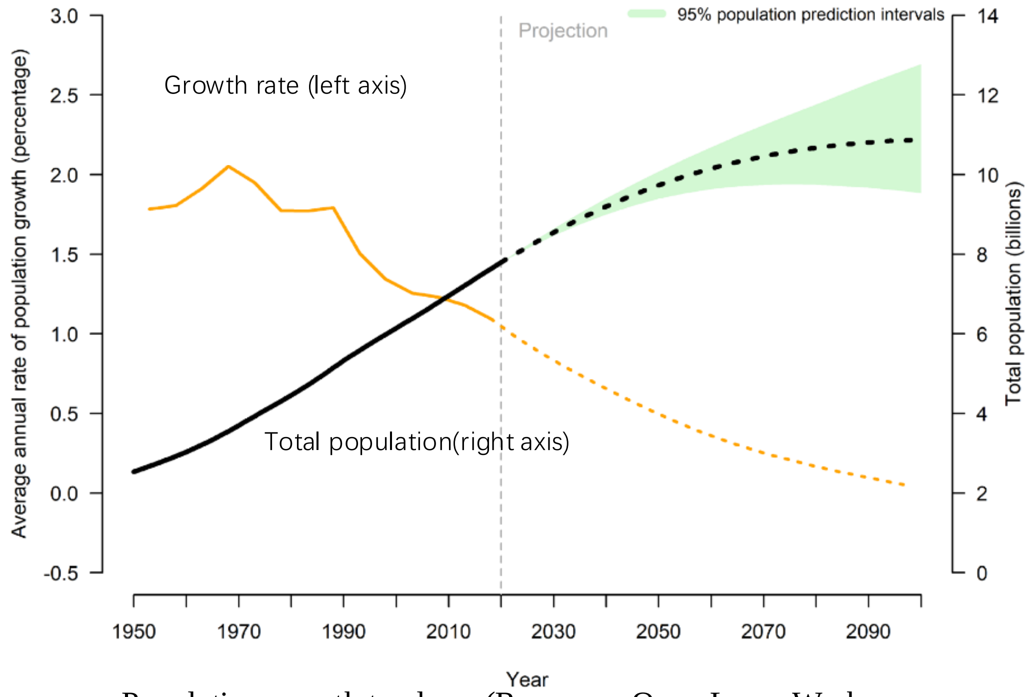
Introduction

➢ Global Challenge

Today's global issues like climate change, energy shortages, increasing environmental pollution, rising population, and rapid urbanization present tremendous challenges to the sustainable development of human society.



Global temperature changes from 1880 to 2020(Resource: NASA earth observatory World of Change)



Population growth tendency(Resource: Open Learn Works Study Session 3 Water Sources and their Characteristics, 2016)

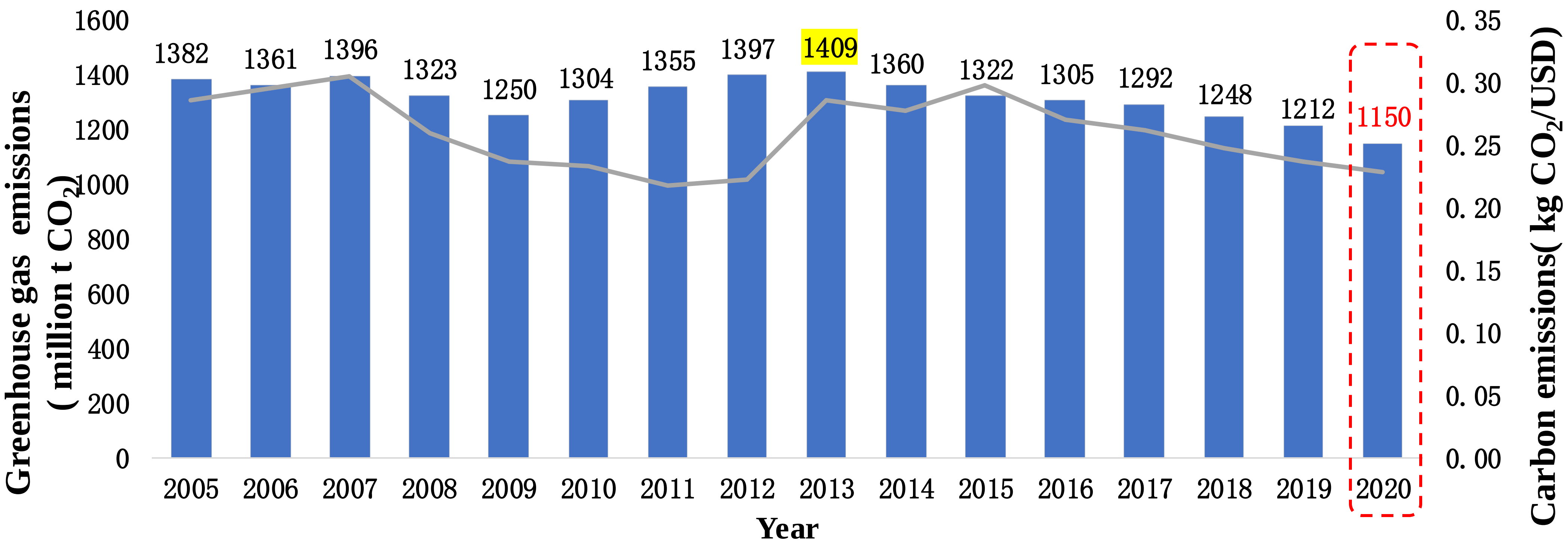
As one of current global challenge, the temperature is close to the highest stage .

The increasing population and increasing urbanization are accelerating the demand for energy that will reach 900 EJ primary energy use in 2050.

➢ EJ is short for Exajoule, EJ=E^{18}J.

Introduction

➢ **Greenhouse Gas Emissions or Carbon Emissions ???**



2020	CO_2 Energy occurred	CO_2 Non energy occurred	CH_4	N_2O	Replace four gases of Freon: HFCs	PFCs	SF_6	NF_3	Total Million t CO_2 (conversion)
Carbon emission	967	76.8	28.4	20	51.7	3.5	2.0	0.29	1150

Total carbon emissions in Japan

(Resource: He WANG, et al. Development and strategy of building carbon neutrality in Japan)

Introduction

➢ Standards

In order to realize the accounting of building carbon emissions, various countries, regions and international organizations have issued various relevant standards, and the main theoretical system and quantitative methods are based on carbon footprint.

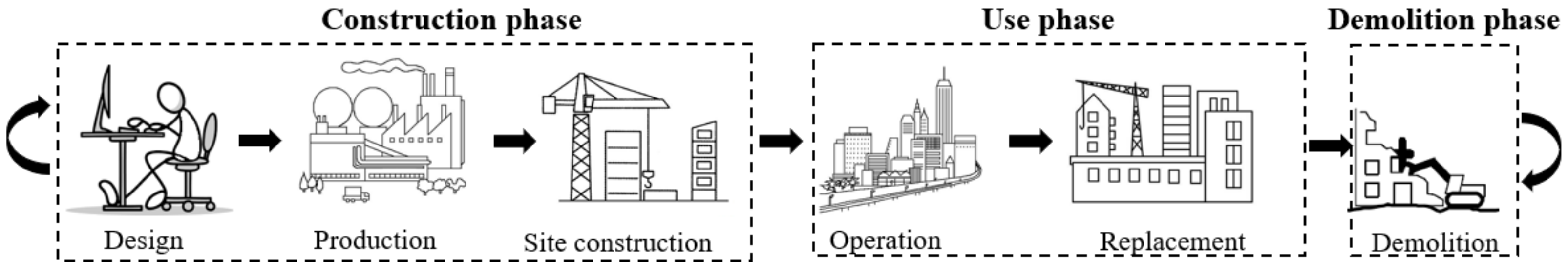
Standard	Release time	Scope	Organization
GHG Protocol Corporate Accounting and Reporting Standard	2004	Company	The World Resources Institute (WRI), World Business Council for Sustainable Development (WBCSD)
Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard	2005	Project	
Corporate Value Chain (Scope 3) Accounting and Reporting Standard	2011	Company	
Product Life Cycle Accounting and Reporting Standard	2011	Product/ Service	
2006 IPCC Guidelines for National Greenhouse Gas Inventory	2006	Country/ Region	Intergovernmental Panel on Climate Change (IPCC)
ISO14064-1	2006	Organization	International Organization for Standardization (ISO)
ISO14064-2	2006	Project	
ISO14064-3	2006	Organization / Project	
ISO14067	2013	Organization	
PAS2050	2008	Product/ Service	British Standards Institute (BSI), Carbon trust, Department for Environment, Food and Rural Affairs (DEFRA)
TS Q 0010	2009	Product/ Service	Japanese Industrial Standards Committee(JISC), Ministry of Economy, Trade and Industry(METI)
GB/T 51366-2019	2019	Product	Ministry of Housing and Urban-Rural Development, State Administration for Market Regulation

Various standards

Introduction

- **Building carbon emissions**

The carbon emissions throughout the lifecycle of a building are divided into embodied carbon emissions and operating carbon emissions (Crowther, n.d.; Ding, 2004).
Embodied carbon emissions include all carbon emissions generated during the production, transportation, construction and demolition of raw materials (Ding, 2004; Koskela, 2018).
Embodied carbon emissions are divided into direct and indirect (Treloar et al., 2001a; Ding, 2004).
Direct carbon emissions refer to the energy consumption and carbon emissions generated by the production or services directly invested in these activities, like construction and transportation. Indirect carbon emissions refers to the energy consumption and carbon emissions generated by the input of materials or services in upstream or downstream processes, such as materials manufacturing and demonstration.
Direct carbon emissions can be considered as a single pathway, while indirect carbon emissions may be several times or even hundreds of times greater, depending on the complexity of the product itself.



Lifecycle of Building

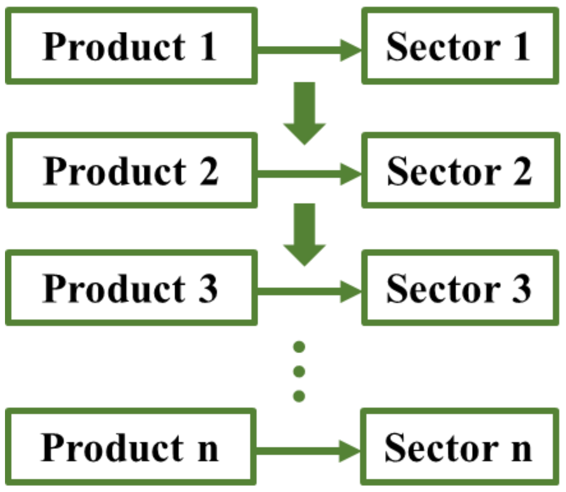
Introduction

➢ Main methods

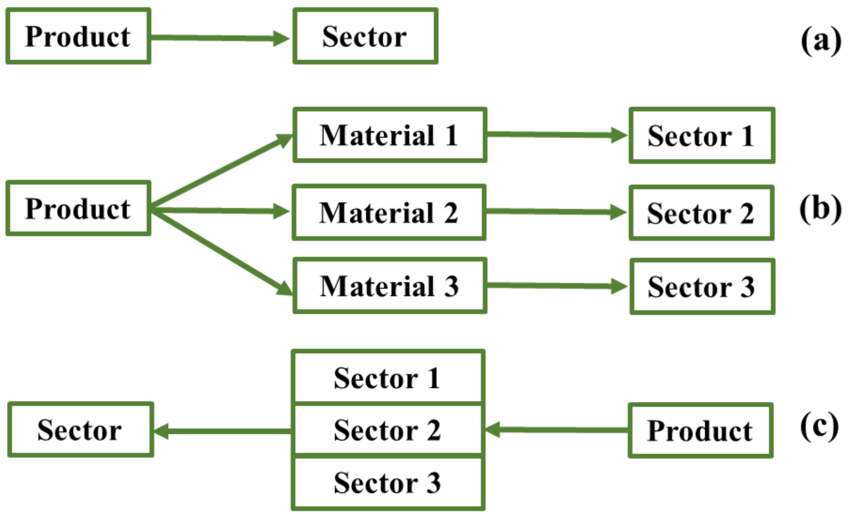
At present, according to different system boundaries and methodological principles, there are three main types of methods according to the carbon footprint accounting methods: Process Life Cycle Assessment (Process-based LCA, PLCA), Input-output Assessment (I-O) and Hybrid Life Cycle Assessment (Hybrid LCA, HLCA).

PLCA is to decompose products or processes into several unit processes, and finally summarize the data to obtain the environmental data of the products or processes.

The input-output(I-O) table is an analytical method reflecting the dependence of the quantity of input and output between various sectors of the economic system studied and created by Leontief in the 1930s .



The schematic diagram of PLCA

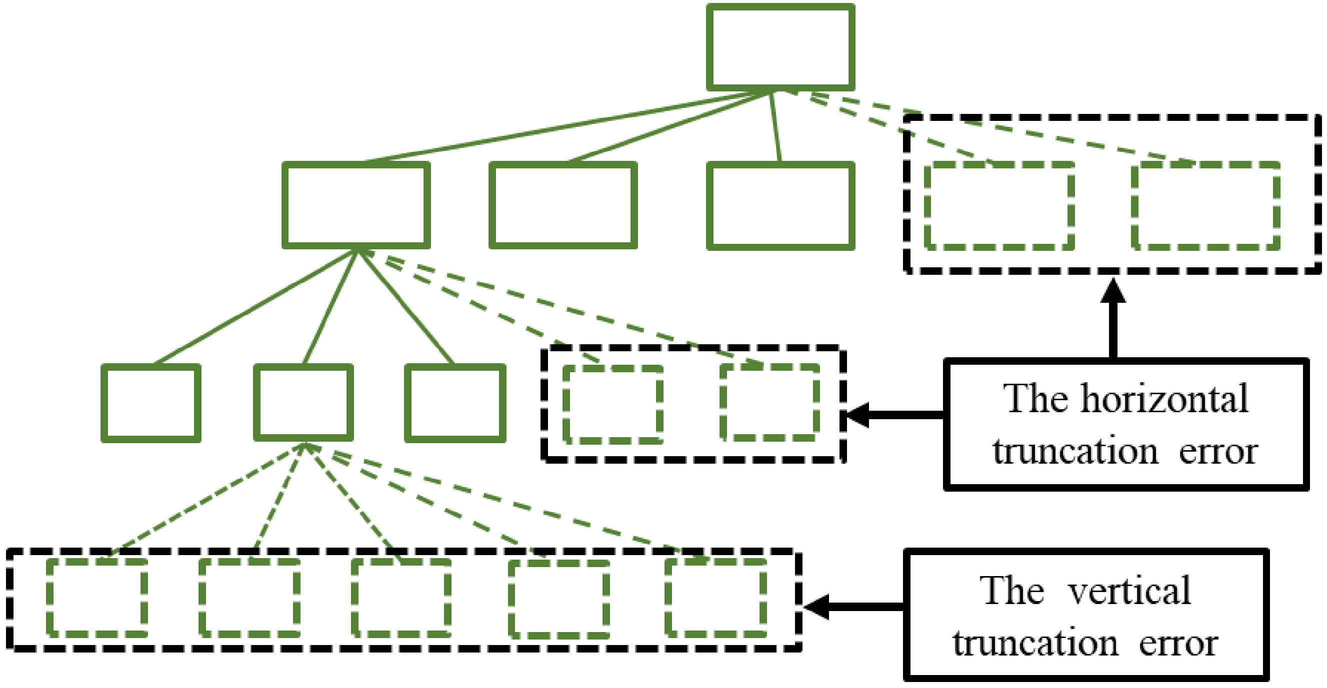


The schematic diagram of I-O LCA

Introduction

➢ The difference between I-O and PLCA model

The difference between the I-O model and the PLCA model is the truncation error in the calculation process. This truncation error includes two aspects, namely horizontal truncation error and vertical truncation error as shown in Figure. Because PLCA cannot collect all the consumption during the inventory analysis process, it is called horizontal truncation error. However, the calculation process cannot calculate the environmental impact of the input from resource extraction to product production. The error caused by the calculation is vertical truncation errors.



The horizontal and vertical truncation error of PLCA method

Introduction

➢ **Detail information of methods**

In this paper, input-output method is used to estimate the carbon emission of Japanese construction industry.
By accounting the carbon emission caused by the final demand of the building construction industry, the structure of carbon emissions in the construction industry and the main sources of carbon emissions in the construction industry are analyzed.

Detail information of three types of life cycle assessment methods

Comparison index	PLCA	I-O	HLCA
Data Sources	Research data	Public data	Research data+ Public data
Results reliability	High	Normal	Depends on the ratio of process data to input-output data
Research boundary	Incomplete	Complete	Complete
Time and cost	Much	Less	High proportion of process data: Much Low proportion of process data: Less
Application convenience	Convenient	Convenient	Complex
Main application range	Case study	Macro Study	Case study and Macro Study

Method and Data

➢ **Detail information of I-O method**

The input–output table is an important tool to analyze the economic and technical relationship between production sectors, which can be traced to the embodied environmental impact of a specific sector of various materials and services.

Input–output table

Output sectors		**Indirect use**				**Final demand**			**Total output**
Input sectors		Sector 1	Sector 2	…	Sector n	Consume	Accumulating capital	Total	
Indirect inputs	Sector 1	X_{11}	X_{12}	…	X_{1n}	II		f_1	X_1
	Sector 2	X_{21}	X_{22}	…	X_{2n}			f_2	X_2
	…	I						…	…
	Sector n	X_{n1}	X_{n2}	…	X_{nn}			f_n	X_n
Value added		V_1	V_2	…	V_n	-			
	…	IV							
	Sector n	V_{n1}	V_{n2}	…	V_{nn}				

The method has become the mainstream method used to study the environmental impact from the macro perspective. Based on the “input = output” theory, the Leontief matrix is used to represent the relationship between the total input and total output.

$$x = (I - A)^{-1} \cdot f = L \cdot f$$

x and f are the total input of the sector and the final demand of the sector;

I is the identity matrix;

$A = [X_{ij}/X_j]_{n\times n}$ is the direct consumption coefficient matrix representing the value of unit i consumed by unit j;

$L = (L_{ij})_{n\times n}$ is the Leontief matrix.

Method and Data

➢ **Detail information of I-O method**

On this basis, the direct carbon emission generated by unit output of each department is introduced, which is defined as row vector d^t, and is the carbon emission directly generated by production of each sector according to the final demand f. The sector's direct carbon emissions are determined by multiplying the amount of fossil fuels consumed by the sector by the calorific value of combustion and the CO2 intensity, respectively. Based on this, the total carbon emission E can be expressed by the behind formula.

$$E = \mathbf{d}^{\mathbf{t}} \cdot \left\{ \mathbf{I} - (\mathbf{I} - \hat{\mathbf{M}}) \cdot \mathbf{A} \right\}^{-1} \cdot \left\{ (\mathbf{I} - \hat{\mathbf{M}}) \cdot \mathbf{f_d} + \mathbf{f_e} \right\}$$

Where f is used to represent the final demand vector of the department, which is divided into domestic demand fd and export demand fe.
In this study, import coefficient matrix M is introduced to exclude the environmental impact of imported products.

Method and Data

➢ Data sources

In this study, Japan's 2020 I-O table at producer's prices is used. Due to the inconsistency between the number of row and column sectors in the table, some sectors need to be merged and finally sorted into a table of 385 sectors. In addition, since the Ministry of Economy Trade and Industry has not released the corresponding Table on value and quantity, the amount of energy consumption for each sector is calculated based on the average price of various energy sources in 2020.

For sources of carbon emissions, this study only considers carbon emissions from the burning of fossil fuels and the decomposition of limestone when applied in industrial fields. In the production process of cement and concrete, due to the release of carbon dioxide caused by the calcination of limestone, the carbon emissions generated by limestone need to be considered.

➢ Definition of building construction

The Japanese input-output table stipulates that the building construction sector consists of Residential construction (wooden), Residential construction (non wooden), Non-residential construction (wooden), and Non-residential construction (non wooden).

Residential construction (wooden) is a type of building that is primarily constructed with wood and is used for residential or commercial purposes.

Its scope includes the new construction, extension, and renovation of such buildings.

Non residential refers to buildings other than residential.

Non wooden is primarily composed of non wood materials.

Results and Discussions

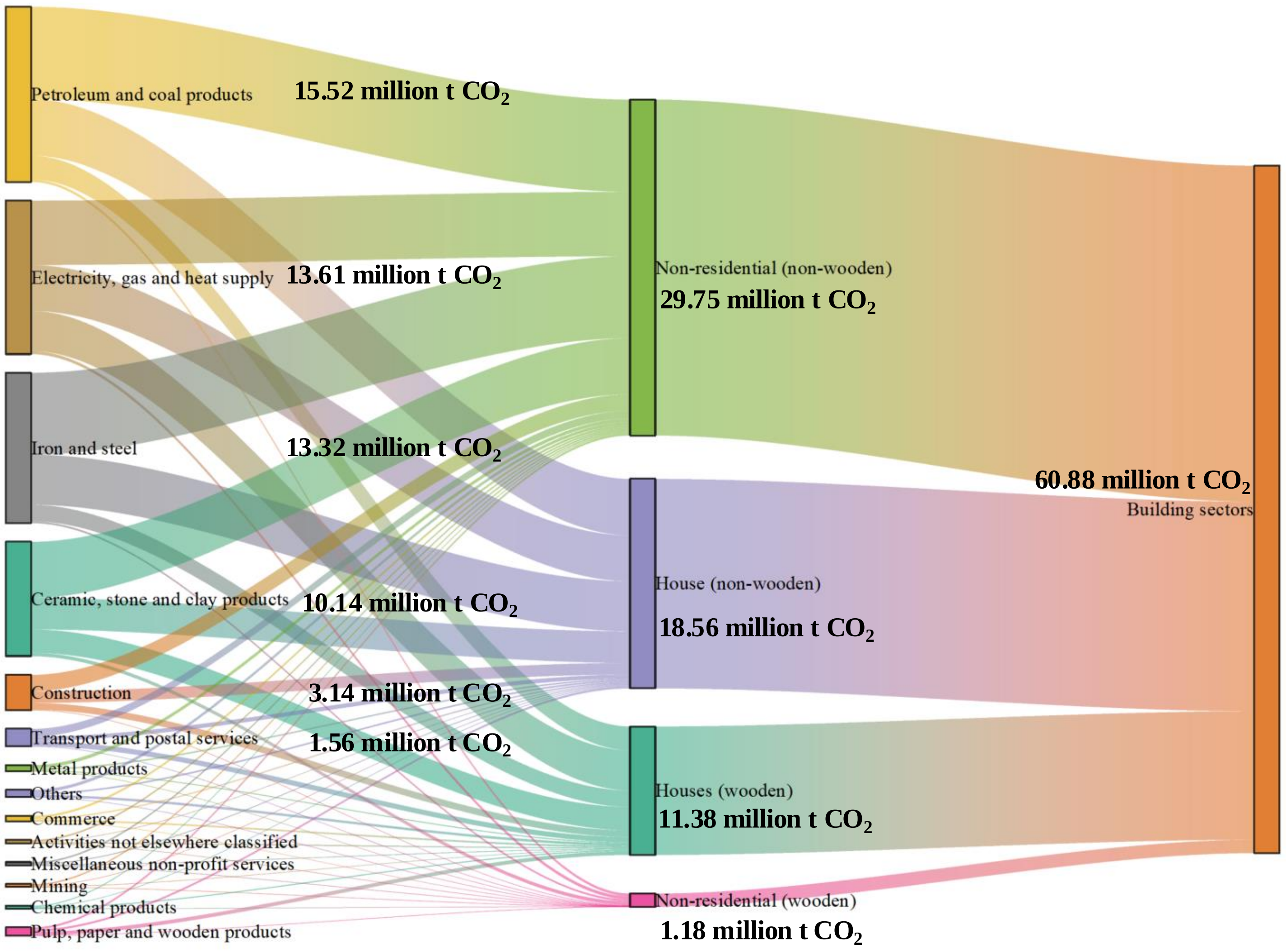
➢ Carbon emission flow

The top six sectors account for 94.1% of the total carbon emissions from the building sector. The petroleum sector accounted for the largest share, at 25.49%, followed by energy supply sectors such as electricity at 22.35%, steel and kiln industry at 21.88% and 16.65%, respectively. The construction and transport sectors contribute 5.2% and 2.8% to carbon emissions, respectively. The rest of the industry accounted for less than 1.5%.

In order to achieve energy saving and reduce carbon emissions, Japan relies on mandatory laws to promote the implementation of relevant policies and programs, and stipulates energy saving and carbon reduction at all stages of the building life cycle.

In the industrial sector, carbon neutrality can be achieved through the practical application of technologies such as hydrogen reduction in ironmaking, carbon dioxide-absorbing concrete, and carbon dioxide-recycling cement.

On the other hand, in sectors requiring high temperatures and energies that are difficult to electrify, carbon neutrality can be achieved by utilizing hydrogen and synthetic methane as fuels.



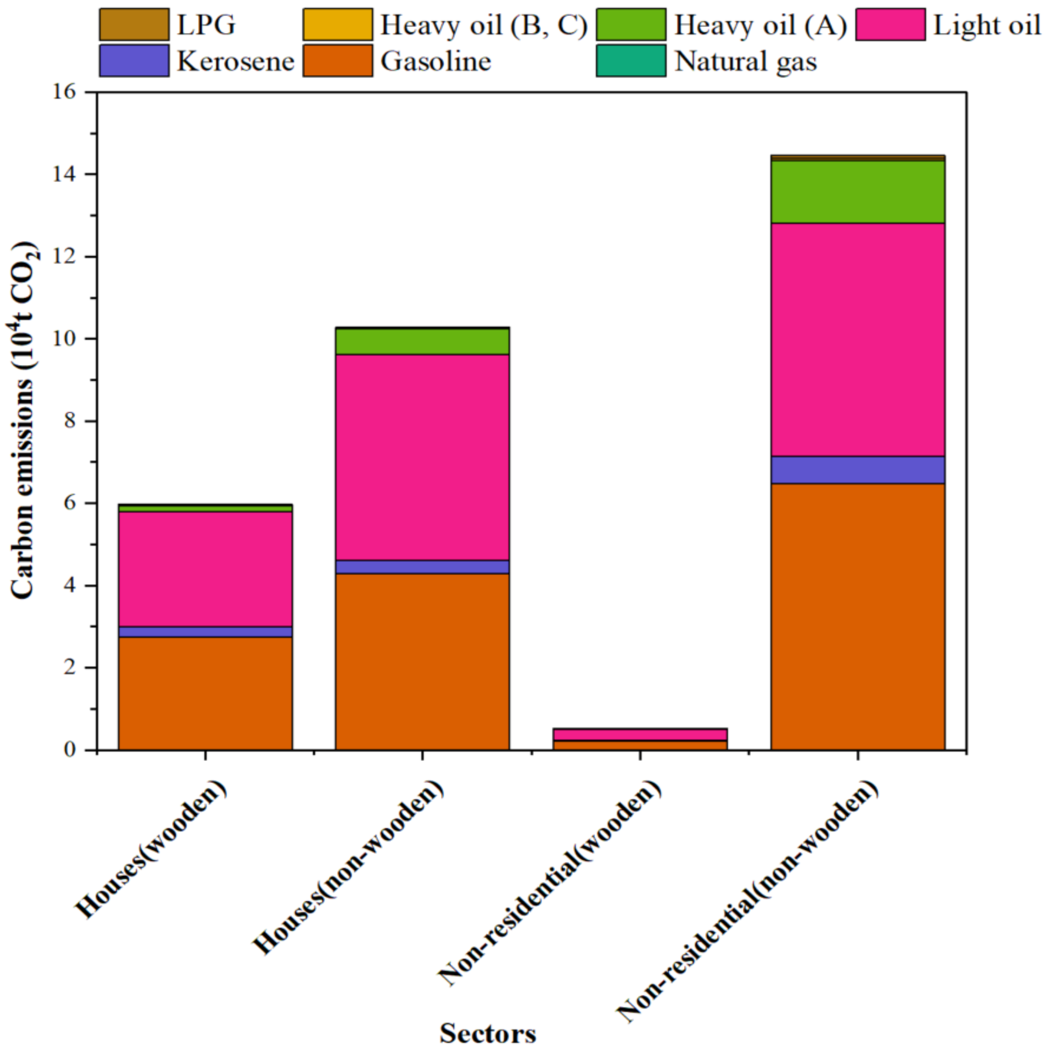
Building construction carbon emission flow path in Japan

Results and Discussions

➢ Direct carbon emissions

The results show that non-residential (non-wood) direct carbon emissions are the highest at 145x10^3 tons, followed by residential (non-wood) at 103x10^3 tons, followed by residential (wood) and non-residential (wood) at 6.0 and 5,000 tons, respectively.

For direct carbon emissions, gasoline and light oil account for the largest proportion, followed by lamp oil and heavy oil, and the rest of the fuel account for a small proportion. Direct carbon emissions come from the consumption of fuel by mechanical equipment in the process of new construction and renovation. Therefore, carbon emission control can be achieved through the use of low-fuel machinery and the expansion of biodiesel, hydrogen and renewable energy. The proportion of local construction materials is expanded to reduce carbon emissions during the transportation of materials. In addition, promoting training personnel to avoid unnecessary idling in vehicle operation and equipment operation are also major measures to reduce carbon emissions.



Direct carbon emissions from four sectors

Thanks for your attention.