Doctoral Dissertation

Comparative Study on Changes in Responsibility for Carbon Dioxide Emissions across Major Cities in Japan

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Abstract

Accounting for approximately 70% of global carbon dioxide (CO_2) emissions, cities can play a critical role in mitigating climate change. Although several carbon accounting methods have been proposed to identify the carbon mitigation responsibility of cities, there is still no single common and widely accepted method.

CO_2 emissions within territorial boundaries and mitigation responsibilities are represent two different aspects for consideration. The former are a place-based phenomenon, while the latter are an attribution or allocation issue. City governments account for the mitigation responsibility for out-of-boundary CO_2 emissions associated with electricity consumption in cities, but they do not use the same methods to assess the embodied CO_2 emissions of other goods and services. How much carbon mitigation responsibility should a city shoulder? Is this amount determined by the definition of its chosen system boundary?

Delineating the system boundary for carbon mitigation responsibility is not an easy task, and it is necessary to better understand the relevant complexities. Although city governments consider system boundaries from various perspectives of production and consumption as well as supply and demand, they should act under different policies.

In this study, we adopted a method that is based on four system boundaries to identify and compare the CO_2 emissions of large Japanese cities, including Tokyo, the capital city. We focused on long-term longitudinal data for major Japanese cities.

First, we summarized the literature on carbon accounting methods and defined the system boundaries approach including consumption-based emissions.

Second, we analyzed the per capita CO_2 emissions of six large Japanese cities in 1980 and 2000. Although substantial differences exist among the 6 large cities in terms of industrial structure and transformation, population, and local climatic conditions, we found that for consumption-based emissions, per capita CO_2 emissions are very similar among them and stable over the 20-year study period, although those for all the other system boundaries are not.

Third, we analyzed the CO_2 emissions of Tokyo in 1990, 1995, 2000, 2005 and 2011. Most of Tokyo's electricity is supplied by the Tokyo Electric Power Company (TEPCO). TEPCO suspended its nuclear power plant for a long period in 2003, the Kashiwazaki-Kariwa Nuclear Power Plant was suspended following the Niigata Prefecture Chuetsu-oki Earthquake in 2007, and the Fukushima Nuclear Power Plant (the first and second power plants) was suspended following the Great East Japan Earthquake in 2011. Due to the suspension of these power plants, the CO_2 emissions embodied in the electricity consumed by Tokyo fluctuated significantly, but there was not much change in consumption-based emissions in Tokyo.

According to these findings, regardless of changes in the energy structure, including the energy supply and industrial structure, the carbon mitigation responsibility of cities was stable. This result contrasts with the general claims made by local authorities regarding their success in reducing CO_2 emissions.

We argue that using consumption-based emissions provides a more realistic account of changes in urban CO_2 emissions and trends and should be adopted by local authorities in their efforts to achieve urban climate change mitigation goals.

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Abbreviations

COP: Conference of the Parties

GHG: Greenhouse gas

GRDP: Gross regional domestic product

GODLCs: Government ordnance-designated large cities

IPCC: International Panel on Climate Change

JOTT: Japan other than Tokyo

SRIO: Single-regional input-output Table

MRIO: Multi-regional input-output

TEPCO: Tokyo Electric Power Company

TMG: Tokyo Metropolitan Government

UNEP: United Nations Environment Programme

UNFCCC: United Nations Framework Convention on Climate Change

WMO: World Meteorological Organization

Chapter 1

Introduction

1.1 What is the role of cities' countermeasures against climate change?

Cities consume approximately two-thirds of global energy and produce over 70% of global CO_2 emissions, even though only approximately half the world's population lives in such locations. City and local governments are seen to have a key role in the mitigation responsibility for CO_2 emissions and in climate policy.

However, city and local governments struggle with their carbon mitigation responsibility and with making policies because it is challenging to estimate how much carbon mitigation responsibility a city should shoulder. For the purpose of examining carbon mitigation responsibility, we need to accumulate fundamental information and develop appropriate measures for cities to consider in addition to existing measures.

The urban economy has a highly externally dependent structure, and goods and services are thus imported. Arguably, cities indirectly consume embodied energy in imported commodities. Therefore, cities are required to pay attention to CO_2 emissions, not only the emissions directly emitted within city boundaries but also the emissions associated with embodied energy.

For example, the industrial transformation of cities is much faster than that of nations. Based on this transformation, the supply and demand structure of goods and services changes with dramatic increases in a city's dependency on external supplies.

Moreover, almost all electricity in cities is supplied from outside their boundaries.

Therefore, due to the power supply procurement method, cities that exceed the national average exhibit large variations in the intensity of electricity-based CO_2 emissions.

Therefore, we discuss the prospects for CO_2 emissions due to changes in the industrial structure and energy structure over a long-term span.

In this study, we approach the issue of the carbon mitigation responsibility of large cities as follows:

1) We discuss carbon accounting methods and define the carbon responsibility of cities and its measurement.

2) We clarify the characteristics of the CO_2 emissions of major cities in Japan, including Japan's capital and six large cities that have different industrial structures and energy supplies.

3) We examine the long-term changes in the CO_2 emissions of major cities in Japan using different carbon accounting methods.

4) We validate carbon mitigation responsibility through calculations using single-regional and multi-regional input-output tables

5) We discuss the carbon mitigation responsibility of major cities in Japan.

1.2 Structure of the dissertation

This structure of this dissertation is presented in Figure 1.

Chapter 1 introduces the purpose and structure of this study and describes the research review on urban carbon mitigation responsibility, and defines the four system boundary approaches used in this study and the carbon mitigation responsibility of cities. Chapter 2 analyzes the changes in the carbon mitigation responsibility of six large Japanese cities that have different industrial structures and energy supplies in order to investigate how changes in urban economic growth and industrial structures are related to CO_2 emissions. Chapter 3 analyzes the changes in the carbon mitigation responsibility of Japan's capital city, Tokyo after power supply shocks due to nuclear power plant accidents in order to examine how the dependence on electricity supply affects their CO_2 emissions. Chapter 4 validates the carbon mitigation responsibility through calculations with single-regional and multi-regional input-output tables. Chapter 5 offers conclusions and policy implications for cities with regard to their emission mitigation responsibilities.

In addition, the study described in Chapter 2 was published in the journal Sustainable Cities and Society in 2020 as "Changes in per capita CO_2 emissions of six large Japanese cities between 1980 and 2000 - An analysis using The Four System Boundaries approach".

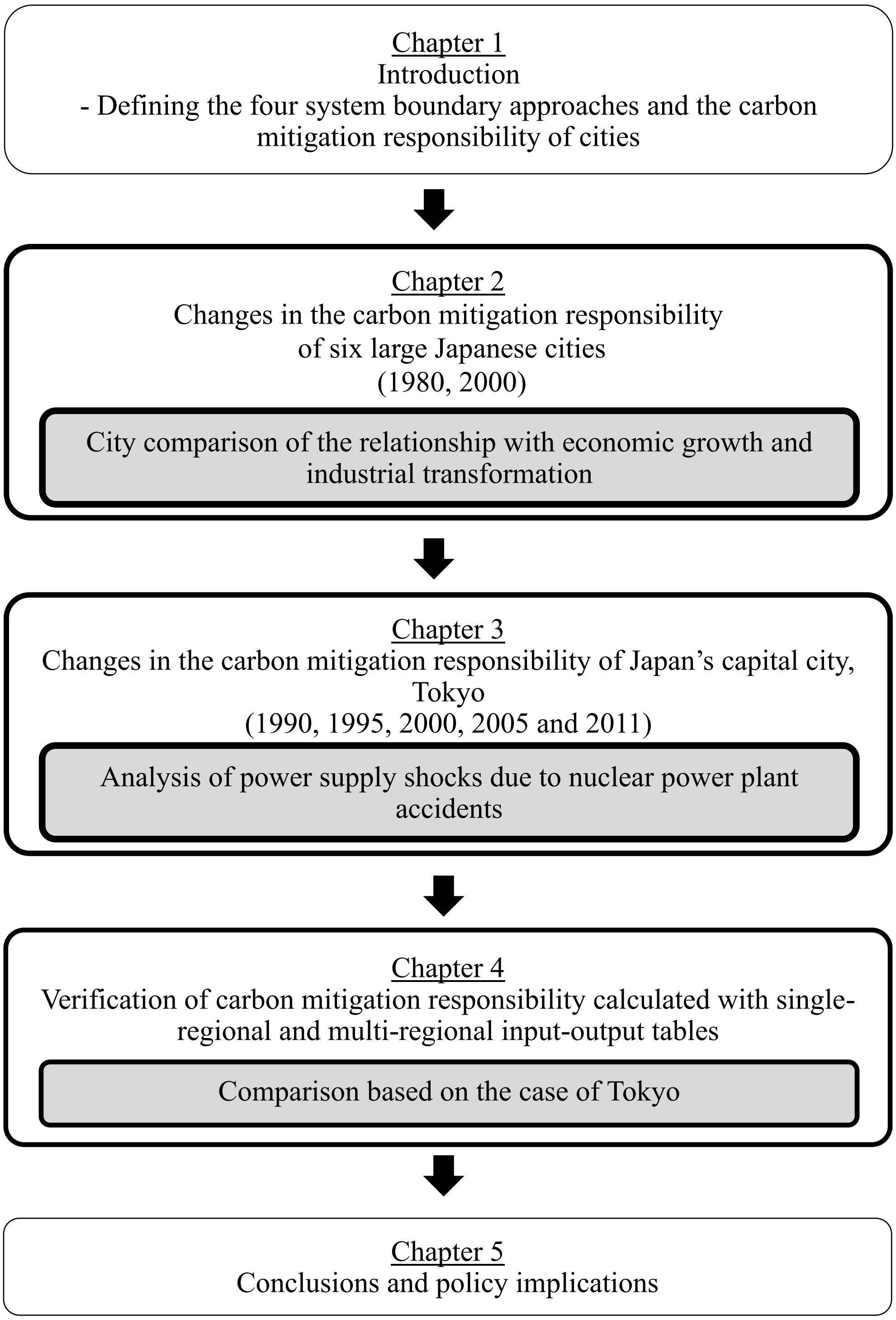


Figure 1. Structure of the dissertation

1.3 Defining carbon mitigation responsibility of cities and its measurement

1.3.1 Carbon accounting methods

At national level, CO_2 emissions inventories are prepared using Guidelines for National Greenhouse Gas Inventories proposed by the IPCC (IPCC, 2006) for reporting to the United Nations Framework Convention on Climate Change (UNFCCC). These CO_2 emission inventories are for their territorial jurisdictions and are used primarily for inter-governmental discussions and negotiations regarding target setting for reducing emissions and for evaluating the progress of emission mitigation policies.

Many other types of carbon accounting methods also exist (Schaltegger & Csutora, 2012; Stechemesser & Guenther, 2012). These methods have been proposed and propagated in academic, business and political arenas and cover aspects that are of interest to different stakeholders. They take account of both direct and indirect or induced emissions. The most widely discussed type highlights the mitigation responsibilities of consumers, who do not necessarily contribute to emission responsibilities under the territorial principle. Consumption-based emissions are estimated by adjusting the emissions embodied in internationally traded commodities (Ahmad & Wyckoff, 2003; Peters, 2008; Peters & Hertwich, 2008) and can be compared with production-based emissions, which are same as those implied by the territorial principle. The concept of consumption-based emissions has an affinity for the export promotion strategies driven by energy-intensive industries of developing countries, especially China, which claim that the carbon mitigation responsibility of nations stipulated by the territorial principle should be discounted (Huimin & Ye, 2010). Note that consumption-based carbon emissions differ from carbon footprints, which are analogous to ecological footprints[1] in the sense that carbon footprints do not consider the carbon emissions embodied in export commodities, which represent outflows and leakage.

Several studies estimate consumption-based CO_2 emission inventories[2] for each country and compile the results at the global scale (Davis & Caldeira, 2010; Davis, Peters, & Caldeira, 2011; Peters, Davis, & Andrew, 2012; Peters, Minx, Weber, & Edenhofer, 2011). Collectively, it is found that the proportion of global emissions embodied in internationally traded commodities has increased from 20% in 1990 to 23% in 2004 and 26% in 2008, due mainly to increases in trade flows from developing countries to developed countries. In addition, 37% of global emissions are from fossil fuels traded internationally. Moreover, studies confirm that the aggregate CO_2 emissions from developing countries have already surpassed those of developed countries, even by consumption-based measures; the same is true of the comparison between China and the US, which are the largest emitters in each group (Le Quéré et al., 2018).

Another type of carbon accounting is based on the assertion that each country should be responsible for its cumulative historical CO_2 emissions since the Industrial Revolution, which is known as the Brazilian proposal in the UNFCCC negotiations (Friman & Linnér, 2008). This accounting is also used for setting long-term emission control goals. Further, Wei et al. (2014) argue that it is more consistent for current

[1] Schulz (2010) provides a carbon footprint analysis of Singapore, which is an open city state, and finds that direct CO_2 emissions are only 20% of the carbon footprint of Singapore.
[2] Here, the term "consumption-based emissions" refers to the System 4 boundaries mentioned later.

governments to be responsible for cumulative CO_2 emissions not from the Industrial Revolution, which represents a common base year, but from their establishment as individual nations. When historical emissions are used as a long-term goal, the study by Wei et al. (2014) shows that the base year significantly affects the allocation of mitigation responsibilities among countries.

Several accounting methods have been proposed that focus on stakeholders other than national governments. Among others, Frumhoff, Heede, and Oreskes (2015) proposes a carbon accounting method that attributes GHG emissions to stockholders to visualize investors' emission responsibilities. This, especially concerns firms engaged in the fossil fuel industry. Evidence suggests that just 90 big companies in the fossil fuel industry are collectively responsible for two-thirds of global GHG emissions (Starr, 2016).

A number of accounting methods have been proposed that have been examined from various perspectives.

1.3.2 Study of CO_2 emissions estimates for Cities

Energy related CO_2 emissions from cities are in the range of 70 to 75% of corresponding global CO_2 emissions (Grubler et al., 2012; International Energy Agency, 2008; Seto et al., 2014). Cities are also expected to play a significant role in adopting sound climate policies that are adapted to local needs and requirements (Betsill & Bulkeley, 2006). In addition, it has been discussed that urbanization, as a phenomenon of collective growth of cities, has heterogeneous effects on national CO_2 emissions depending on the stage of development (Chikaraishi et al., 2015; Poumanyvong & Kaneko, 2010) and thus policy prescription is not so simple.

Urban carbon accounting lags far behind national-level carbon accounting. This is explained by issues such as difficulties in defining the boundaries of cities (as open systems); availability and accessibility of comprehensive, verifiable and comparable data; lack of experienced staff to create local emission inventories; and costs associated with acquiring data and hiring data analysts (Creutzig et al., 2018; Gurney et al., 2015).

Due to these issues, existing studies have mainly concentrated on the production of data on city-scale emissions of CO_2 and other greenhouse gases (as shown in Table 1). In an earlier study, Baldasano et al. (Baldasano, Soriano, & Boada, 1999) estimated CO_2 emissions in the city of Barcelona from 1987 to 1996 and discussed how the emissions increased. More recently, several studies have collected data on and provided estimates of energy consumption and CO_2 emissions in cities such as Bangkok (Phdungsilp, 2010), Kathmandu (Shrestha & Rajbhandari, 2010), and Indianapolis (Gurney et al., 2012). Relevant within-country comparative studies include those of Brown, Southworth, and Sarzynski (2009), who assessed emissions of CO_2 from the 100 most populous municipal areas in the US; Dhakal (2009), who assessed CO_2 emissions from 35 cities and 4 megacities, Beijing, Shanghai, Tianjin and Chongqing, in China; Minx et al. (2013), who estimated carbon footprint of many cities in the UK; and Chen et al. (2017) and Tong et al. (2018) who compiled and analyzed CO_2 emissions data for many Chinese cities; Ramachandra, Aithal, and Sreejith (2015) reported the results of GHGs accounting for multiple cities in India. Long et al. (2020a) examined the trends in CO2 emissions in Japanese prefectures from 2007 to 2011. Relevant international comparative studies include those of Kennedy et al. (2009, 2010), who assessed emissions of GHGs from 10 selected megacities worldwide. Also, in the recent years, several online platforms have been developed for self-reporting of emissions by cities across the world. Examples are the Carbon Discloser Project (https://www.cdp.net) and the Carbon Climate Registry platform (http://carbonn.org/).

In addition to these articles, which focus primarily on city-scale carbon emission estimates, information on carbon emission estimates is obtained as part of earlier step of further in-depth analyses. Examples include a discussion of urban policies related to mitigation measures for CO_2 emissions from Rio de Janeiro, especially with the benefit of clean development mechanisms (CDMs) (Dubeux & Rovere, 2007) and modeling studies that investigate the development of emission reduction roadmaps for Kyoto (Gomi, Ochi, & Matsuoka, 2010), Shanghai (Li et al., 2010) and Kathmandu (Shrestha & Rajbhandari, 2010).

Table 1. Study of CO_2 emissions estimates for cities

Authors	Cities, Country
Baldasano et al. (1999)	Barcelona, Spain
Brown et al. (2009)	Cities, U.S.
Chen et al. (2017)	Cities, China
Dhakal (2009)	Cities, China
Dubeux and Rovere (2007)	Rio de Janeiro, Brazil
Gomi, Ochi et al (2010)	Kyoto, Japan
Gurney et al. (2012)	Indianapolis, U.S.
Kennedy et al. (2009, 2010)	Megacities, worldwide
Li et al (2010)	Shanghai, China
Long et al. (2020a)	Prefectures, Japan
Minx et al. (2013)	Cities, U.K.
Phdungsilp (2010)	Bangkok, Thailand
Ramachandra et al (2015)	Cities, India
Shrestha & Rajbhandari (2010)	Kathmandu, Nepal
Tong et al. (2018)	Cities, China

1.3.3 Carbon accounting methods for cities

City governments are not directly involved in international negotiations, and the emission inventories of cities reported in the literature are not standardized or comparable. This is because such inventories have not been prepared using consistent accounting methods and data collection/analysis protocols. However, several initiatives have been taken to clarify emission boundaries and develop consistent carbon accounting methods. The Global Protocol for Communities (GPC) is one such initiative that is developed by major urban stakeholders with the aim of standardization of emission accounting (https://ghgprotocol.org/greenhouse-gas-protocol-accounting-reporting-standard-cities). This protocol classifies carbon accounting methods into three categories. 1) Scope 1 refers to direct CO_2 emissions generated within the administrative boundary of a city, from sources such as transportation and building heating. 2) Scope 2 accounts for CO_2 emissions embodied in the electricity supplied to the city from outside its administrative boundaries. Finally, 3) Scope 3 refers to all other CO_2 emissions embodied in all commodities, including electricity, supplied to the city from outside its administrative boundaries[3]. Building on this approach, Liu et al. (2015) introduced a fourth scope (Scope 4) that accounts for all emissions except for those embodied in product exports. Based on these four scopes, they developed a "four system boundaries" approach for emission accounting.

As illustrated in Figure 2, we redefined the fourth scope (Scope 4) as the embodied emissions in export commodities and the four system boundaries are related to the

[3] Emissions determined using Scope 3 are equivalent to carbon footprints.

previously-mentioned scopes as follows: System boundary 1 (hereafter refers to SB-1) and Scope 1 are identical to each other, system boundary 2 (SB-2) equals the sum of Scope 1 and Scope 2 emissions, system boundary 3 (SB-3) equals the sum of Scope 1 and Scope 3 emissions, and finally system boundary 4 (SB-4) equals to the sum of Scope 1 and Scope 3 minus Scope 4 (all emissions minus export-related ones). The fourth system boundary is comparable to the consumption-based emissions concept used in international comparisons of national emissions. We use the four boundaries from the SB-1 to the SB-4 in the rest of study.

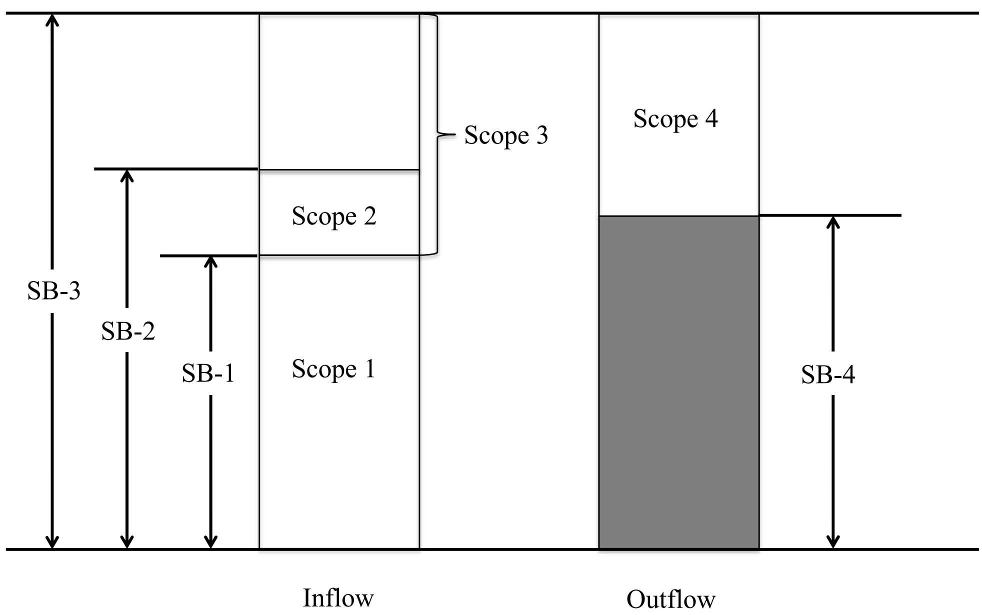


Figure 2. Scope and system boundaries (SBs) of this study

Although most of the above-mentioned city-scale studies focus on SB-1 and SB-2 emissions, the number of studies that measure carbon footprints (which are equivalent to SB-3) has recently increased (as shown in Table 2). Larsen and Hertwich (2009) apply SB-

3 to municipal services for the city of Trondheim and find that 93% of the city's CO_2 emissions are indirect. Hillman and Ramaswami (2010) estimate and compare carbon emission inventories using SB-3 boundaries for eight cities in the US (although, for the major cross-boundary inflows, accounting for indirect emissions is partially approximated by bottom-up approaches). With more comprehensive coverage, Kennedy et al. (2010) compared different carbon accounting methods across SB-1, SB-2, and SB-3 for 10 cities worldwide. In the study case of Japan, Hasegawa et al. (2015) found that SB-1 is often different from SB-4 in Japanese prefecture. Long and Yoshida (2018) analyzed the CO_2 emissions of Tokyo clarified that SB-3 is about twice as high as SB-1.

The number of studies that estimate and report carbon emissions using the "four system boundaries" is limited at the city scale, although there are many such studies at the national scale. Liu et al. (2015) adopted the "four system boundaries" approach to estimate and compare emissions of 30 cities and regions in China. The study on Singapore mentioned above (Schulz, 2010), also employs the "four system boundaries" approach. The author argues that this approach is more relevant for discussing the mitigation responsibilities of cities than countries, as the openness of the economic structure of cities is higher, and greater proportions of their CO_2 emissions are induced outside of their administrative boundaries.

Several studies have attempted to improve our understanding of the empirical characteristics of carbon inventories derived using the "four system boundaries" approach. For example, considering the relationship between city-scale economic indicators and carbon inventories obtained using the four system boundaries, Minx et al. (2013) analyzed emissions of British cities. They examine the relationship between emissions and income, household size, and the level of education of the head of the household. Similarly, Sudmant, Gouldson, Millward-Hopkins, Scott, and Barrett (2018) examine the gap between the emissions determined using SB-1 and SB-4 and discuss their relationships with income level and population density for cities in the US, the UK and China. Moreover, Feng, Hubacek, Sun, and Liu (2014) discusses the gap between the emissions obtained using SB-1 and SB-4 while elaborating in detail on the trade between large cities and their surrounding regions in China.

Table 2. Comparative research of carbon accounting methods for cities

Authors	Cities, Country	Scope1	Scope2	Scope3	Consumption Based Emissions
Feng et al (2014)	Cities, China	○	○	○	
Hasegawa et al. (2015)	Prefectures, Japan	○		○	
Hillman and Ramaswami (2010)	Cities, U.S.	○	○	○	
Kennedy et al. (2010)	Cities, worldwide	○	○	○	
Larsen and Hertwich (2009)	Trondheim, Norway	○	○	○	
Liu et al (2015)	Cities in China	○	○	○	○
Long and Yoshida (2018)	Tokyo	○	○		○
Minx et al. (2013)	Cities, U.K.	○	○	○	
Schulz (2010)	Singapore	○		○	○
Sudmant,et al (2018)	Cities, U.S., U.K., and China	○	○	○	

1.3.4 Carbon mitigation responsibility for cities

In practice, “four system”-based carbon accounting methods are infrequently applied to set goals for urban climate policies. For example, in Japan, Article 21 of the 2004 Act for the Promotion of Global Warming Countermeasures requires prefectural and municipal governments to formulate local action plans for the mitigation of GHG emissions. In these plans, specific goals must be set. In most cases, carbon accounting is performed using SB-2 as a typical target, and thus, only the CO_2 emissions embodied in imported electricity are considered. Moreover, the action plans concentrate on building awareness through campaigns and school-based educational programs to promote energy savings, particularly for electricity use. Such efforts are not necessarily new and have been implemented since the oil crisis in the 1980s.

As mentioned above, carbon accounting using the "four system boundaries" approach has been frequently applied at the national level, mainly due to the increasing availability of global input-output tables, which make it possible to calculate the intensities of CO_2 or GHG emissions embodied in internationally traded commodities based on major commodity groups and for each country. Meanwhile, although the national average embodied emission intensity can approximate the intensity of the import of commodities into cities, determining the city-specific intensities of commodities exported from each city requires the use of input-output tables. Thus, the application of SB-3 to cities is much less costly and more practically feasible than the application of SB-4.

SB-1 and SB-2 are responsible only for production-side emissions, not for consumption-side emissions. SB-3, which is the total amount of direct emissions plus indirect emissions, makes both the transferring exporter and the transferring importer responsible for CO_2 emissions.

SB-4, which is consumption-based emissions, is not a territorial principle of the IPCC but a way of thinking in which the final consumer of goods and services is responsible for all CO_2 generated in production and distribution, regardless of where it is emitted. The concept of SB-4 exempts the exporting side from responsibility and places all other responsibility on the end-consuming side. Thus, this study defines SB-4 as the carbon mitigation responsibility of cities.

When SB-4 is set as a reduction target, we must aim to reduce not only the emissions of the city in question but also indirect CO_2 emissions, which will accelerate the promotion of global warming countermeasures.

Although it is still a costly approach, we investigate the homogeneity and long-term stability of the measurements of the four system boundaries approach for major cities in Japan to accumulate empirical evidence and improve our understanding of the fundamental characteristics of the carbon emissions of cities based on the four system boundaries approach.

These cities have followed different trajectories in terms of their economic growth, industrial transformation and electric power supply methods.

Against this backdrop, we would like to see how the emissions of these cities with different system boundaries have evolved over the study period. In particular, we aimed to determine whether there were differences in emissions between SB-4 and the other system boundaries (SB-1, SB-2 and SB-3).

1.4 Climate change efforts of Japanese local governments

The International Panel on Climate Change (IPCC), cosponsored by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO), was established in November 1988 as the first official intergovernmental effort to review the scientific aspects of global warming. The IPCC provides government decision-makers with the most reliable scientific and technical knowledge on how international measures are progressing.

Subsequently, in December 1990, the United Nations established the UNFCCC, which began deliberations at the UNFCCC Negotiating Conference, and 155 countries, including Japan, signed the convention at the Earth Summit held in the same year.

In the 1980s, the destruction of the ozone layer, deforestation, acid rain, and global warming became apparent, and it became necessary for the government of Japan to comprehensively address global environmental issues as an important international problem. After the establishment of the IPCC in 1988, the Director General of the Environment Agency was appointed the Minister of State for Global Environment Affairs, and a domestic structure was put in place in July 1990. As a result of these developments, the "Action Plan for the Prevention of Global Warming" was formulated in October 1990. This action plan clarified the Japanese government's policy regarding the systematic and comprehensive promotion of global warming countermeasures and the overall picture of possible future measures.

In 1997, Japan presided over the Third Conference of the Parties (COP) for the UNFCCC. At this conference, the "Kyoto Protocol" was adopted, which established numerical targets and policy measures for emission reductions in developed countries. The protocol introduced new mechanisms, such as the Kyoto Mechanisms.

Following the adoption of the Kyoto Protocol at COP3, the "Law Concerning the Promotion of Measures to Cope with Global Warming" was promulgated on October 9, 1998. This law established a framework for the national government, local governments, businesses, and citizens to work together to combat global warming. Additionally, also encouraged not only national and local governments but also businesses that emit large amounts of CO_2 to prepare plans and disclose their implementation status. Furthermore, it included the promotion of detailed measures by local governments in accordance with local conditions rather than nationwide efforts.

In response, since the late 1990s, local governments in Japan have begun to promote global warming countermeasures in earnest. In accordance with the Law Concerning the Promotion of Measures to Cope with Global Warming, local governments are required to formulate "local government action plans", and many local governments have started estimating their CO_2 emissions.

Furthermore, in 2008, the Law Concerning the Promotion of Measures to Cope with Global Warming was revised to further promote global warming measures. The amendments included the following: 1) a review of the system for calculating, reporting, and announcing greenhouse gas emissions; 2) the establishment of guidelines for reducing emissions; 3) the promotion of initiatives to reduce greenhouse gas emissions in daily life; 4) the clarification of credit compensation procedures for new afforestation and reforestation CDM projects; and (5) the enhancement of the action plans of local governments.

Based on the Paris Agreement adopted at COP21 and Japan's draft commitment submitted to the United Nations in July 2015, the cabinet approved the Global Warming Prevention Plan, a plan to comprehensively and systematically promote Japan's global warming countermeasures, on May 13, 2016.

This plan clarified the measures to be taken by each entity and the government to achieve the mid-term target of a 26% reduction by 2030 compared to the 2013 level, and it provided a roadmap for achieving the reduction target. It also set a long-term goal of reducing greenhouse gas emissions by 80% by 2050 compared to the 2013 level, which would be the cornerstone of Japan's global warming countermeasures.

In 2021, the cabinet approved a bill to partially revise the Law Concerning the Promotion of Measures to Cope with Global Warming. The purpose of this bill was to increase the continuity and predictability of policies, accelerate decarbonization efforts, investment and innovation, and promote decarbonization efforts using local renewable energy and decarbonization management by corporations by specifying in the law the realization of carbon neutrality by 2050

As mentioned above, with rapidly changing environmental and social conditions, Japanese local governments are required to implement a wide variety of policies. Estimates of CO_2 emissions are used as indicators for planning and evaluating these policies. For this reason, the estimates of CO_2 emissions is an extremely important indicator for local governments. In this paper, we will compare the four-system boundary for CO_2 emissions from different perspectives with the aim of understanding the structure of urban CO_2

emissions and to enable municipalities to formulate and evaluate policies that take into account not only the production side but also the consumption side.

Chapter 2

Changes in the carbon mitigation responsibility of six large Japanese cities - Intercity comparison of the relationship with economic growth and industrial transformation

2.1 Background and objectives

The industrial transformation of cities is much faster than that of nations. Based on this transformation, the supply and demand structure of goods and services changes with dramatic increases in a city's dependency on external supplies.

Therefore, we analyze the changes in the carbon mitigation responsibility of six large Japanese cities that have different industrial structures and energy supplies. To consider the influence of economic growth and industrial transformation and to identify and compare the per capita CO_2 emissions of six large Japanese cities in 1980 and 2000, we adopted a method based on four system boundaries.

This chapter compares CO_2 emissions in terms of 1) six large cities in Japan that have different industrial structures, 2) long-term changes between 1980 and 2000, and 3) different carbon accounting methods applied to consumption-based emissions.

2.2 Context of large cities in Japan

2.2.1 Large cities: Government Ordinance-Designated Large Cities (GODLCs)

Cities are defined differently in different countries. In Japan, article 8 of the Local Autonomy Act defines the required lower-bound conditions for local administrative units to be entitled as a city. First, the unit should have a population greater than 50,000. Second, a central area of the unit should have more than 60% buildings and facilities. Third, more than 60% of households in the unit should have at least one family member who is working in secondary or tertiary industries. In addition to these three requirements, the unit should satisfy the additional requirements specified by the local ordinance of the prefectural government. There were 210 cities at the time the Act was introduced in 1947, and the number increased to 651 in 1985 and further to 791 in 2018. Before 1985, new cities have been formed mostly by urban migration and population growth. However, after 1985, new cities have essentially been formed by merging towns and villages following the policies of the central government. Since the second condition is very vague and the share of agriculture in the Japanese labor market became less than 10% in the early 1980s, the conditions are not obstacles for towns and villages to be upgraded to cities. In other words, there is an increasing number of “cities”, which are not largely different from towns and villages, particularly those that have become cities since 1985 when the population growth rate was already low.

Other definitions in the same Act are also given for larger cities. Currently, the Act allows government ordinance to designate two types of special large cities: large cities with a population of 500,000 or greater and core cities with a population of 200,000 or greater[4].

Although city governments are under the supervision of the prefectural government, Government Ordinance-Designated Large Cities (GODLCs) have special authorities and the same amount of political power as prefectures. Moreover, these cities have been granted a large level of local autonomy, especially regarding preparation and implementation of urban plans and policies. The designation of large cities has been practices since 1956, whereas that of core cities is relatively new and was introduced in 1995. There were 5 GODLCs in 1956, Osaka (2.55), Nagoya (1.34), Kyoto (1.20), Yokohama (1.14) and Kobe (0.98), where the numbers in parentheses represent the population in millions at the time of designation. In 1963, Kitakyushu (1.04) was added to the GODCs, and three more cities, Sapporo (1.01), Kawasaki (0.97), Fukuoka (0.85), were included in the GODLCs in 1972. The 10th GODLCs was Hiroshima (1.04), which was added in 1980. Thus, there were 10 GODLCs as of 1980. Currently, there are 20 GODLCs.

2.2.2 Characteristics of the six large cities

Among the 10 GODLCs, which were designated by 1980, the six cities of Sapporo, Yokohama, Kobe, Hiroshima, Kitakyushu and Fukuoka City were selected to be examined in this study. Data availability was the main criterion for selecting these six cities. These cities are spatially distributed throughout the country, as shown in Figure 3. The socioeconomic profiles in 1980 and 2000 are summarized in Table 3. It is noted that due to

[4] The Tokyo Metropolitan Government (TMG) is treated differently by the special ward system, 23 wards are designated in the TMG as fundamental administrative units.

data unavailability of single-regional Input-Output table (SRIO) in 1980 of Hiroshima City, all the data of Hiroshima throughout the study are in 1985.

Figure 3. Geographic location of the selected cities

Table 3. Characteristics of the selected cities

		Sapporo	Yokohama	Kobe	Hiroshima	Kitakyushu	Fukuoka
Geography							
Area(km2)	1980	1,118	427	542	737	477	336
	2000	1,121	435	550	742	484	339
Average temperature (Feb.	1980	-5.7	4.8	3.8	3.5	4.2	5.1
in °C)	2000	-3.8	5.6	4.7	4.7	5.3	6.1
Average temperature (Aug.	1980	19.0	23.0	25.5	24.3	24.0	24.5
in °C)	2000	23.9	27.2	29.1	28.6	28.3	28.6
Demography							
Population (million	1980	1.40	2.77	1.37	1.04	1.07	1.09
people)	2000	1.82	3.43	1.49	1.13	1.01	1.34
Economy							
GRDP (trillion-yen,	1980	3.1	5.6	3.7	3.3	2.7	3.4
nominal)	2000	7.2	12.8	6.3	5.5	4.1	6.5
Per capita GRDP (million-	1980	2.2	2.0	2.7	3.2	2.5	3.1
yen, nominal)	2000	3.9	3.7	4.2	4.9	4.0	4.9
Total gross (trillion-yen,	1980	5.3	13.0	8.0	6.2	7.0	5.8
nominal)	2000	11.4	22.5	11.1	9.3	7.6	10.5
Manufacturing (%)	1980	30.0	55.1	49.0	40.1	63.9	24.4
	2000	15.3	34.4	32.0	28.1	40.2	16.8
Import (trillion-yen,	1980	1.3	6.2	3.6	2.7	2.6	2.4
nominal)	2000	3.9	9.3	4.3	3.7	2.9	3.7
Export (trillion-yen,	1980	-1.6	-7.0	-3.4	-2.3	-2.2	-1.6
nominal)	2000	-3.4	-9.6	-4.1	-2.7	-2.5	-2.7
Energy							
Total final energy	1980	23.1	122.2	92.5	29.5	257.8	29.6
consumption (Exa J)	2000	47.3	150.7	83.0	41.2	220.9	42.2
Per capita energy	1980	16.4	44.1	67.6	28.2	242.1	27.2
consumption (Mega J)	2000	26.0	44.0	55.6	36.6	218.4	31.5
Electricity in final energy	1980	23.0	15.7	15.5	28.9	13.2	22.4
consumption (%)	2000	38.1	24.4	24.7	35.3	15.6	39.9
Petroleum products in final	1980	58.8	65.1	34.5	43.3	30.7	58.1
energy consumption (%)	2000	38.2	53.1	20.6	32.8	17.7	34.6
Coal products in final	1980	12.6	7.8	47.0	16.9	51.8	13.2
energy consumption (%)	2000	14.3	8.0	45.4	23.8	54.5	14.8
Gas products in final	1980	5.5	11.4	3.0	10.9	4.3	6.3
energy consumption (%)	2000	9.4	14.5	9.3	8.1	12.3	10.6

Note: All data of Hiroshima is 1985.

Data sources: Statistical Council of Large Cities of Japan. (various years) and Ministry of Economy, Trade and Industry of Japan. (various years).

Sapporo located in a subarctic climate, where large heating energy is required during the winter season. The other five cities are located within a narrow latitude range and have similar climatic characteristics, even though the distance between Yokohama and Fukuoka is approximately 1,000 km. Sapporo has the largest administrative area, which is also different from the others, while Hiroshima is the second largest and Fukuoka is the smallest. In contrast, Yokohama is the largest in terms of population size and economic activity, and Kitakyushu is the largest with respect to final energy consumption. While Kitakyushu is the only city that experienced population decline between 1980 and 2000, the final energy consumption was reduced in two cities during the same period: Kobe and Kitakyushu. In addition, the per capita final energy consumption was reduced in three cities: Yokohama, Kobe, and Kitakyushu.

Although industrial transformation toward a service-oriented economic structure is common to all six cities, the stages are slightly different from one city to another. While manufacturing was the dominant sector in Yokohama, Kobe and Kitakyushu in 1980 and Hiroshima in 1985, the share of manufacturing in Sapporo and Fukuoka was less than 35%. Most of the cities, except Kitakyushu, have reduced their manufacturing share to less than 35% in 2000. The per capita gross regional domestic product (GRDP) of Yokohama was the lowest both in 1980 and 2000, even when the growth rate for the 20-year span was the highest. While Hiroshima had the highest per capita GRDP in 1980 and 2000, but the growth rate for the 20-year span was the lowest, as was Kitakyushu. The inter-city gaps of per capita GRDP have been reduced from 1.6 to 1.3. Imports are larger than exports for all of the six cities, except Yokohama.

As the most influential factors in determining carbon emission profiles, total final energy consumption, per capita final energy consumption and structure of final energy consumption by source are compared in Table 1. The large discrepancies can be found both in total energy consumption and per capita final energy consumption across the six cities, although the gaps between the largest and the smallest have been reduced from 11.2 to 5.4 and 14.7 to 8.4 times, respectively. While the energy sources are also different from city to city and although Sapporo and Fukuoka have relatively similar energy source structures, the direction of the changes in the structure of final energy consumption is similar. On the one hand, the shares of electricity and gas have been increased for all selected cities, except for Hiroshima where the share of gas was not increased and coal was exceptionally increased during the period. On the other hand, petroleum products have been lost in all six cities.

In summary, the disparities across the six cities have declined for many indicators from 1980 to 2000. However, large differences still exist for many key potential determinants of CO_2 emissions.

2.3 Methodology

The methodological basis of the empirical analysis discussed in this study originates in energy Input-Output analysis, a method that has become well established and widely applied since the 1970s (e.g., Bullard & Herendeen, 1975; Bullard, Penner, & Pilati, 1978; Costanza, 1980; Costanza & Herendeen, 1984). Similar methods are currently intensively applied to studies in the fields of lifecycle assessment, carbon leakage issues in climate change studies and/or trade and the environment studies to measure embodied carbon emissions (for example, Ahmad & Wyckoff, 2003).

With reference to Nansai, Moriguchi, and Tohno (2002), the basic model for specifying the intensity of embodied CO_2 emissions and the carbon balance of an open economy is described as follows. First, using column-wise data obtained from an SRIO, the balance of CO_2 emissions in sector *j* can be expressed in terms of ε_k, the intensity of CO_2 emissions embodied in the products of sector *k*; $x_{i,j}$, the domestic intermediate inputs from sector *i* to sector *j*; X_j, the total output of sector *j*; and D_j, the direct CO_2 emissions from sector *j*:

$$\varepsilon_j X_j = \varepsilon_1 x_{1,j} + \varepsilon_2 x_{2,j} + \cdots + \varepsilon_k x_{k,j} + \cdots + \varepsilon_n x_{n,j} + D_j. \tag{1}$$

With introduction of the relations $a_{i,j} = {x_{i,j}}/{X_j}$ and $d_{ij} = {D_j}/{X_j}$, Equation (1) can be changed to

$$\varepsilon_j = \varepsilon_1 a_{1,j} + \varepsilon_2 a_{2,j} + \cdots + \varepsilon_k a_{k,j} + \cdots + \varepsilon_n a_{n,j} + d_j. \tag{2}$$

Using matrix and vector notation to extend entire sectors, Equation (2) is expressed as:

$$(\varepsilon_1 \quad \varepsilon_2 \quad \cdots \quad \varepsilon_n) = (\varepsilon_1 \quad \varepsilon_2 \quad \cdots \quad \varepsilon_n)\begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1,n} \\ a_{21} & a_{22} & \cdots & a_{2,n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n,1} & a_{n,2} & \cdots & a_{n,n} \end{pmatrix} + (d_1 \quad d_2 \quad \cdots \quad d_n). \tag{3}$$

In the competitive type of SRIO, m_i is an import coefficient to the total supply of products *i* and can be specified using the following formula:

$$m_i = \frac{M_i}{\sum_{j=1}^{n} a_{i,j} X_j + F_i^d} \tag{4}$$

where M_i is the total value of imported product *i*, $\sum_{j=1}^{n} a_{i,j} X_j$ represents the total intermediate demand for product *i*, and F_i^d is the domestic final demand for product *i*.

To differentiate imported products from domestically produced intermediate products, Equation (3) can be further extended by introducing λ_k, the intensity of CO_2 emissions embodied in the imported products of sector *k*:

$$\begin{aligned} (\varepsilon_1 \quad \varepsilon_2 \quad \cdots \quad \varepsilon_n) = {} & (\varepsilon_1 \quad \varepsilon_2 \quad \cdots \quad \varepsilon_n)\begin{pmatrix} 1-m_1 & 0 & \cdots & 0 \\ 0 & 1-m_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & 1-m_n \end{pmatrix}\begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1,n} \\ a_{21} & a_{22} & \cdots & a_{2,n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n,1} & a_{n,2} & \cdots & a_{n,n} \end{pmatrix} \\ & + (\lambda_1 \quad \lambda_2 \quad \cdots \quad \lambda_n)\begin{pmatrix} m_1 & 0 & \cdots & 0 \\ 0 & m_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & m_n \end{pmatrix}\begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1,n} \\ a_{21} & a_{22} & \cdots & a_{2,n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n,1} & a_{n,2} & \cdots & a_{n,n} \end{pmatrix} \\ & + (d_1 \quad d_2 \quad \cdots \quad d_n). \end{aligned} \tag{5}$$

With a vector of intensities of CO_2 emissions embodied by domestic products $\boldsymbol{\varepsilon}$ and that for imported products λ, a diagonal matrix of import coefficients $\hat{M}$, an input coefficient matrix *A*, a vector of direct CO_2 emissions per unit production ***d*** and the identity matrix *I*, Equation (6) can be expressed as:

$$\varepsilon = \varepsilon(I - \hat{M})A + \lambda\hat{M}A + d. \quad (6)$$

Solving Equation (6) with respect to ε yields. $[(I - (I - \widehat{M})A]^{-1}$ is called "Leontief's inverse matrix" and is the basic matrix for opened-type input-output analysis.:

$$\varepsilon = [\lambda\widehat{M}A + d][(I - (I - \widehat{M})A]^{-1}. \quad (7)$$

Then, using row-wise data from an SRIO with the given intensity of CO_2 emissions embodied by product *i*, the balance of CO_2 emissions of domestically produced products in sector *i* can be obtained:

$$\begin{aligned} \varepsilon_i X_i &= \varepsilon_i(1-m_i)\{x_{i,1} + x_{i,2} + \cdots + x_{i,k} + \cdots + x_{i,n}\} \\ &\quad + \varepsilon_i(1-m_i)F_i^d + \varepsilon_i EXP_i \\ &= \varepsilon_i(1-m_i)\sum_{j=1}^{n} x_{i,j} + \varepsilon_i(1-m_i)F_i^d + \varepsilon_i EXP_i \end{aligned} \quad (8)$$

where EXP_i is the export of product *i* that is produced domestically.

Integrating both sides of Equation (8), we obtain:

$$\sum_{i=1}^{n} \varepsilon_i X_i = \sum_{i=1}^{n}\sum_{j=1}^{n} \varepsilon_i(1-m_i)x_{i,j} + \sum_{i=1}^{n} \varepsilon_i(1-m_i)F_i^d + \sum_{i=1}^{n} \varepsilon_i EXP_i. \quad (9)$$

Similarly, in reference to Equation (2) using column-wise data from an SRIO:

$$\varepsilon_j X_j = \sum_{i=1}^{n} \varepsilon_i(1-m_i)x_{i,j} + \sum_{i=1}^{n} \lambda_i m_i x_{i,j} + D_j. \quad (10)$$

Integrating both sides of Equation (10) once again, we obtain:

$$\sum_{j=1}^{n} \varepsilon_j X_j = \sum_{j=1}^{n}\sum_{i=1}^{n} \varepsilon_i(1-m_i)x_{i,j} + \sum_{j=1}^{n}\sum_{i=1}^{n} \lambda_i m_i x_{i,j} + \sum_{j=1}^{n} D_j. \quad (11)$$

Based on Equations (9) and (11) and considering the control totals principle, which is written as $\sum_{i=1}^{n} \varepsilon_i X_i = \sum_{j=1}^{n} \varepsilon_j X_j$, the following balance is obtained:

$$\sum_{j=1}^{n}\sum_{i=1}^{n}\lambda_i m_i x_{i,j} + \sum_{j=1}^{n} D_j = \sum_{i=1}^{n}\varepsilon_i (1-m_i) F_i^d + \sum_{i=1}^{n}\varepsilon_i EXP_i. \tag{12}$$

The left side of Equation (12) represents the input, total CO_2 emissions associated with domestic production, whereas the right side indicates the final destinations of the CO_2 emissions embodied in the domestic products.

Equation (12) captures the balance of CO_2 emissions associated with domestic production processes. However, to construct a more comprehensive balance of the CO_2 emissions associated with city activities, two other forms of CO_2 emissions that are not related to domestic production must be considered. One such form of CO_2 emissions is the CO_2 emissions embodied in the imported commodities that are supplied directly to the final demand sector, whereas the other involves direct CO_2 emissions from the final demand sector. Examples of this second form include CO_2 emissions produced by private vehicles and the combustion of fuel for cooking and heating at home.

When the above-mentioned two types of CO_2 emissions are added for both the inputs and the distribution of the carbon balance of the economy without altering anything, Equation (13) is obtained:

$$\begin{aligned}&\sum_{j=1}^{n}\sum_{i=1}^{n}\lambda_j m_j x_{i,j} + \sum_{j=1}^{n} D_j + \sum_{j=1}^{n}\lambda_j m_j F_j^d + D_F \\ &= \sum_{i=1}^{n}\varepsilon_i (1-m_i) F_i^d + \sum_{i=1}^{n}\varepsilon_i EXP_i + \sum_{i=1}^{n}\lambda_i m_i F_i^d + D_F.\end{aligned} \tag{13}$$

where $\sum_{i=1}^{n}\lambda_j m_j F_j^d$ and $\sum_{i=1}^{n}\lambda_i m_i F_i^d$ are the CO_2 emissions embodied in the imported commodities for both the inputs and the distribution, respectively. D_F represents the aggregate direct CO_2 emissions in the final demand sector.

2.4 Boundary setting and model application

This study applies common alternative simplified methods to establish boundaries between countries and cities, for which the embodied CO_2 emissions intensities are computed separately by SRIO model. This study then applies the above-mentioned methodology to both countries and cities as a simplified Input-Output approach to capture the virtual flows of carbon emissions of cities. First, the CO_2 emissions embodied in goods and services or by sector are measured using the Input-Output model at the national level to capture indirect CO_2 emissions. Note that the influxes of goods and services into a city from domestic and overseas sources cannot be easily differentiated, due to the limitations of the data. Therefore, national average intensities of embodied CO_2 emissions are used as the best available proxy indicators to capture the indirect CO_2 emissions embodied in the goods and services imported by cities.

2.5 Data

Two primary sources of data, SRIOs and energy balance tables of study cities, are used in the empirical analysis presented in this study.

SRIOs are collected directly from each local government as paper-based documents and converted into digital format[5]. The number of endogenous sectors in the original Input-Output tables used in the analysis are summarized in Table 4. In the energy Input-Output analysis, these numbers are usually constrained by the availability of per-sector data on energy consumption, which is much less detailed. The availability of energy data is summarized in Table 5, and regional energy balance tables for the 6 cities are generated using available data sources. The energy balance tables of cities are generated mainly based on digital archives of "Current Survey on Market Structure of Petroleum Products (in Japanese) (Ministry of Economy, Trade and Industry of Japan. (various years)) as these surveys include not only prefectural data but those of the GODLCs. Other supplementary materials used for completing energy balance tables are various paper-based documents and books, including data books that compile information on household energy consumption and statistical data on power stations (Office of Gas Market Development, Agency for National Resources and Energy, Ministry of Economy, Trade and Industry (ed.). (1980, 1985, 2000), Electricity and Gas Division, Agency for National Resources and Energy, Ministry of Economy, Trade and Industry of Japan (ed.). (1980, 1985, 2000), Jyukankyo Research Institute Inc. (2009)). The energy and CO_2 for the empirical analysis

[5] Some has been published online or paper-based and some are internal documents of local governments. However, we collected all these Input-Output tables in the form of paper-based documents.

were estimated using these energy balance tables and based on the CO_2 emission intensity of the Ministry of the Environment for each year.

Considering the availability of data on sectoral energy consumption, a common unified sector classification of SRIOs is established to permit coherent empirical analysis among the 6 cities (as shown in Table 6). The SRIOs from all of the selected cities are separated and combined to create twenty-four compatible sectors.

For the national level analysis, the Input-output tables and energy balance tables are both available with much more detail information (Administrative Management Agency (1980), Management and Coordination Agency (2000), Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry of Japan. (various years)). We then edited national data to be consistent with city level analysis.

Table 4. Sectors of endogenous transactions in original input-output tables of six cities

	1980	1985	2000
Japan (national)	28 (13)	32 (15)	32 (14)
Sapporo	31 (13)	-	31 (12)
Yokohama	36 (21)	-	32 (14)
Kobe	30 (17)	-	34 (16)
Hiroshima	-	31 (15)	33 (15)
Kitakyushu	43 (29)	-	32 (14)
Fukuoka	31 (14)	-	32 (11)

＊ Numbers shown in parentheses indicate manufacturing industrial sectors.

Table 5. Energy balance table calculated for various statistics

Sector	Industrial classification	coal	Natural Gas, Oil	Petroleum and coal products	electricity	City gas	Notes
Conversion	Electricity	※1	※1	※1			※1 Statistical Tables of Electrical Power (Overview of Electricity Supply)
	Gas	※2	※2	※2			※2 Statistical Tables of Gas (Annual report of gas business)
Industry	Agriculture and fishery	※3	※3	※3	※3	※3	
	Mining	※3	※3	※3	※3	※3	
	Food, beverages, feed and tobacco	※4	※4	※4	※5	※4	
	Textile industry; garments and related products	※4	※4	※4	※5	※4	※3 Estimation using national values
	Wood and wood products; furniture and fixtures	※4	※4	※4	※5	※4	※4 Surveys of Energy Consumption in Commerce, Mining and Manufacturing (consumption of each fuel)
	Chemical products	※4	※4	※4	※5	※4	
	Petroleum and coal products	※4	※4	※4	※5	※4	
	Ceramics and stone and clay products	※4	※4	※4	※5	※4	
	Iron and steel	※4	※4	※4	※5	※4	※5 Survey of Energy Consumption in Commerce, Mining and Manufacturing (electricity consumption)
	Nonferrous metals	※4	※4	※4	※5	※4	
	Metal products	※4	※4	※4	※5	※4	
	General machinery	※4	※4	※4	※5	※4	※6 Energy Handbook for Households
	Electric machinery	※4	※4	※4	※5	※4	
	Transportation machinery	※4	※4	※4	※5	※4	※7 Comparison of statistical tables of large cities
	Precision machinery	※4	※4	※4	※5	※4	
	Other manufactured products	※4	※4	※4	※5	※4	
Civil	Households	※6	※6	※6	※6	※6	
	Automobiles			※7			
	Businesses	※1	※1	※1	※1	※1	

Table 6. Unified sector classification for six cities

Sector		Industrial classification
Nonmanufacturing	1	Agriculture and fisheries
	2	Mining
Manufacturing	3	Food, beverages, feed and tobacco
	4	Textile industry; garments and related products
	5	Wood and wood products; furniture and fixtures
	6	Chemical products
	7	Petroleum and coal products
	8	Ceramics and stone and clay products
	9	Iron and steel
	10	Nonferrous metals
	11	Metal products
	12	General machinery
	13	Electric machinery
	14	Transportation machinery
	15	Precision machinery
	16	Other manufacturing products
Construction	17	Construction
Service	18	Electricity, gas and water
	19	Commerce
	20	Finance and insurance
	21	Real state
	22	Traffic and communication
	23	Public administration
Unclassified	24	Other

2.6 Results

2.6.1 Emission inventories produced using the four system boundaries approach

Per capita emissions inventories produced using the four system boundaries approach are estimated for the selected cities in 1980 and 2000, and cross-city and historical comparisons are made (see Table 7 for detailed results). Industrial cities, such as Kitakyushu, demonstrate higher per capita emissions when SB-1 and SB-2 are used. This indicates the suitability of utilizing these two system boundaries for capturing the responsibilities imposed by the direct CO_2 emissions associated with the production activities. On the other hand, those cities with relatively larger-scale economies, such as Yokohama and Kitakyushu, show large per capita carbon footprints as measured using the SB-3. The consumer cities with relatively smaller economies show greater amounts of per capita emissions when the SB-4 is used, compared to the emission values obtained using the SB-1 and SB-2.

Figure 4 displays the per capita emissions obtained using each of the carbon accounting methods in 1980 and 2000 as boxplots. In general, the cross-city variance decreases slightly from 1980 to 2000. During this period, all of the cities have shifted towards being consumer cities with service-oriented industrial structures. Furthermore, the largest cross-city variation is found using the measurements based on the SB-3, whereas that obtained using the SB-4 is fairly small, indicating that the emission inventories obtained using the SB-4 are homogeneous across the different cities and are stable over time.

Table 7. CO_2 emissions of cities estimated using different accounting methods

<Total CO_2 emissions> Unit: million t- CO_2

1980	SB-1	SB-2	SB-3	SB-4
Sapporo	4.1	4.9	12.5	10.2
Yokohama	18.2	12.8	41.9	17.0
Kobe	8.1	10.3	24.5	8.7
Hiroshima	2.7	4.0	12.3	6.1
Kitakyushu	27.9	26.7	37.2	7.8
Fukuoka	2.7	3.8	10.3	6.5

2000	SB-1	SB-2	SB-3	SB-4	Estimates by local governments
Sapporo	6.9	9.7	19.2	14.3	11.3
Yokohama	24.2	18.5	48.5	24.7	19.8
Kobe	7.4	10.5	24.4	10.9	10.2
Hiroshima	3.7	5.9	15.8	8.0	6.3
Kitakyushu	22.8	23.0	38.8	7.8	15.2
Fukuoka	3.8	6.4	14.6	10.3	6.4

<Per capita CO_2 emissions> Unit: t- CO_2

1980	SB-1	SB-2	SB-3	SB-4
Sapporo	2.9	3.5	8.9	7.3
Yokohama	6.6	4.6	15.1	6.1
Kobe	6.0	7.6	17.9	6.4
Hiroshima	2.6	3.8	11.8	5.9
Kitakyushu	26.2	25.1	35.0	7.3
Fukuoka	2.5	3.5	9.5	5.9

2000	SB-1	SB-2	SB-3	SB-4	Estimates by local governments
Sapporo	3.8	5.3	10.5	7.9	6.2
Yokohama	7.1	5.4	14.2	7.2	5.8
Kobe	4.9	7.0	16.4	7.3	6.8
Hiroshima	3.3	5.3	14.0	7.1	5.6
Kitakyushu	22.5	22.7	38.3	7.8	15.0
Fukuoka	2.8	4.8	10.9	7.7	4.8

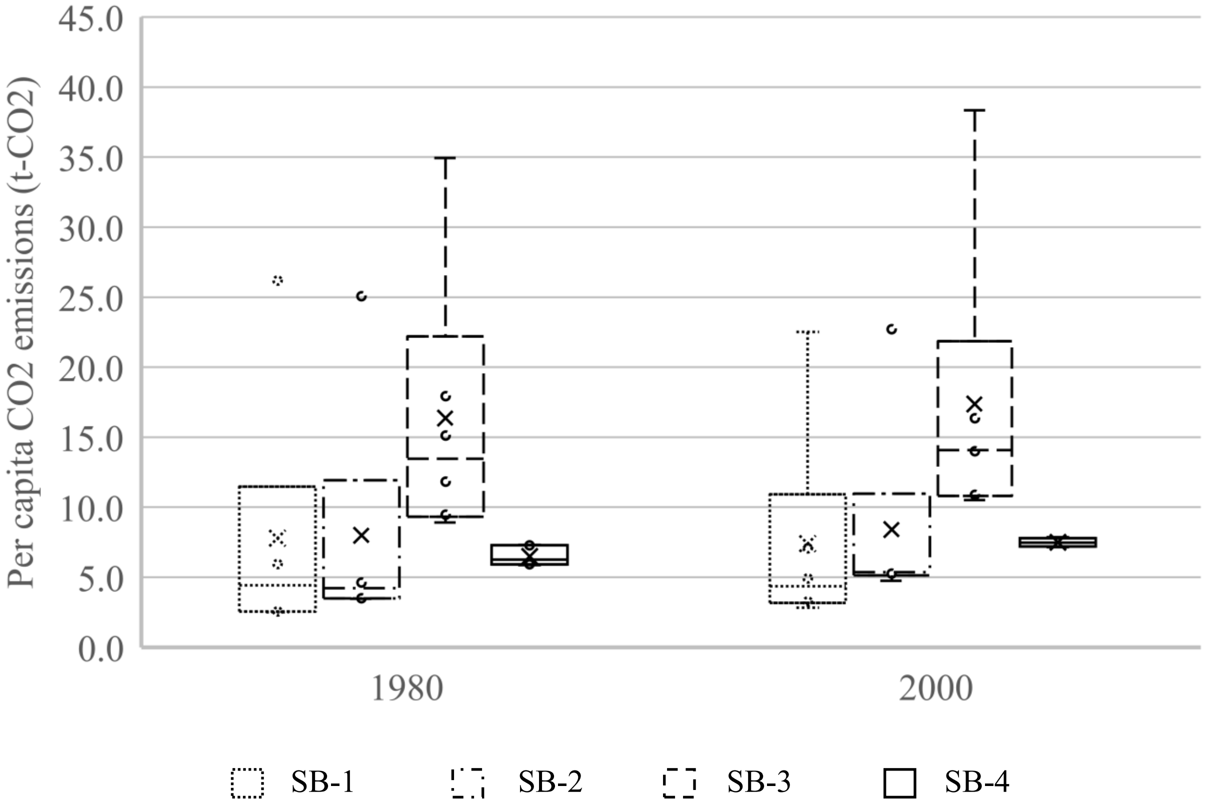


Figure 4. Changes in the cross-city comparison of per capita CO_2 emissions estimated using different accounting methods

2.6.2 Industrial structures and emission inventories for individual cities

During the 1980s and 1990s in Japan, the common direction of the industrial transformation of cities was toward consumer cities or service-oriented industrial structures. Likewise, the 6 selected cities have shifted in the same direction. Consequently, the decline in industrial sectors, especially energy-intensive subsectors (EISSs), is a common and visible phenomenon (as shown in Table 8). In this study, we define five industrial sectors, “chemistry”, “petroleum and coal products”, “ceramics, stone and clay products”, “iron and steel”, and “electricity, gas and water”, as the EISSs. Figure 5 shows the relationship between the share of EISSs in the industrial sector, as measured by value added and different boundaries of carbon accounting (from SB-1 to SB-4). The carbon accounting methods for the SB-1 to SB-3 are largely explained by their linear correlation with the share of EISSs, whereas the carbon accounting of the SB-4 is not related at all. This result confirms that the SB-4 represents a method of assessing consumption-based emissions performance that is not affected by production-related factors.

Table 8. Share of energy-intensive subsectors (EISSs) in the industrial sector

	Average annual change					
	Chemical products	Petroleum and coal products	Ceramics and stone and clay products	Iron and steel	Electricity, gas and water	Total
Sapporo	0.047	-0.034	-0.077	-0.034	0.008	0.002
Yokohama	-0.050	-0.035	-0.045	-0.106	-0.010	-0.036
Kobe	0.018	-0.045	-0.017	-0.078	0.011	-0.035
Hiroshima	-0.045	-1.000	-0.034	0.000	0.002	-0.007
Kitakyushu	-0.025	-0.089	-0.008	-0.046	-0.011	-0.037
Fukuoka	-1.000	0.000	-0.045	-1.000	-0.019	-0.025

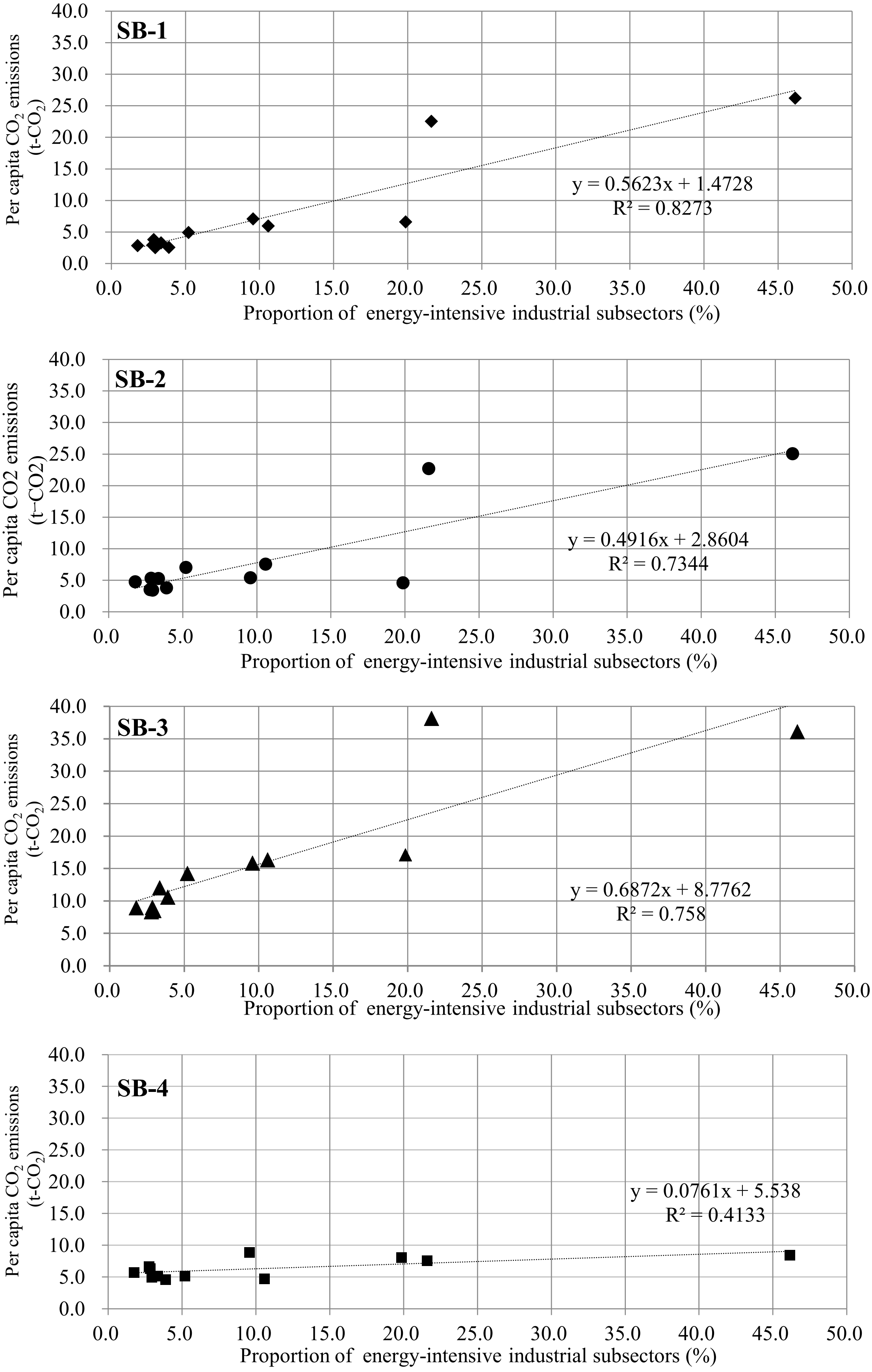


Figure 5. Per capita CO_2 emissions and the share of energy-intensive subsectors

2.7 Summary of findings

The two major findings of this empirical study are summarized below.

1) The per capita CO_2 emissions obtained using the SB-4 exhibit very small cross-city variations amongst large cities in Japan. This is despite the fact that these cities feature different industrial structures ranging from industrial cities to service-oriented ones. In contrast, per capita CO_2 emissions calculated using the SB-1, SB-2 and SB-3 are significantly affected by the industrial structure of cities.

2) The per capita CO_2 emissions obtained using the SB-4 are stable over the 20-year study period (1980-2000). Over this period, the selected cities have reduced their shares of EISSs to different degrees.

Chapter 3

Changes in the carbon mitigation responsibility of Japan’s capital city, Tokyo - Analysis of power supply shocks due to nuclear power plant accidents

3.1 Background and objectives

Tokyo is the capital of Japan and the hub of the country’s economic and administrative activities. To maintain the momentum of sustained economic growth, Tokyo is transforming the structure of its economic activities, the efficiency of production and the patterns of consumption. As a consequence of this economic transformation, the supply and demand structure of energy and material has been changing over time with a dramatic increase in the external dependency of supply.

In particular, Tokyo depends on the supply of TEPCO, which has power plants outside of Tokyo’s boundaries. However, TEPCO suspended its nuclear power plant for a long period in 2003, Kashiwazaki-Kariwa Nuclear Power Plant was suspended following Niigata Prefecture Chuetsu-oki Earthquake in 2007, and the Fukushima Nuclear Power Plant (the first and second power plants) was suspended following the Great East Japan Earthquake in 2011.

Therefore, we analyze the changes in the carbon mitigation responsibility of Tokyo, the capital of Japan, after the electricity supply shock caused by the nuclear power plant accident, and examine how dependence on electricity supply affects CO_2 emissions.

This chapter compares CO_2 emissions in terms of 1) the changes in Tokyo's electricity supply, 2) the changes in 1990, 1995, 2000, 2005, and 2011, and 3) different carbon accounting methods applied to consumption-based emissions.

3.2 Context of Japan's capital city, *Tokyo*

The capital city of Japan is Tokyo, which has a central position in the country, as shown in Figure 6. Tokyo has a temperate climate that is the standard Japanese climate.

The socioeconomic profiles in different years between 1990 and 2011 are summarized in Table 9.

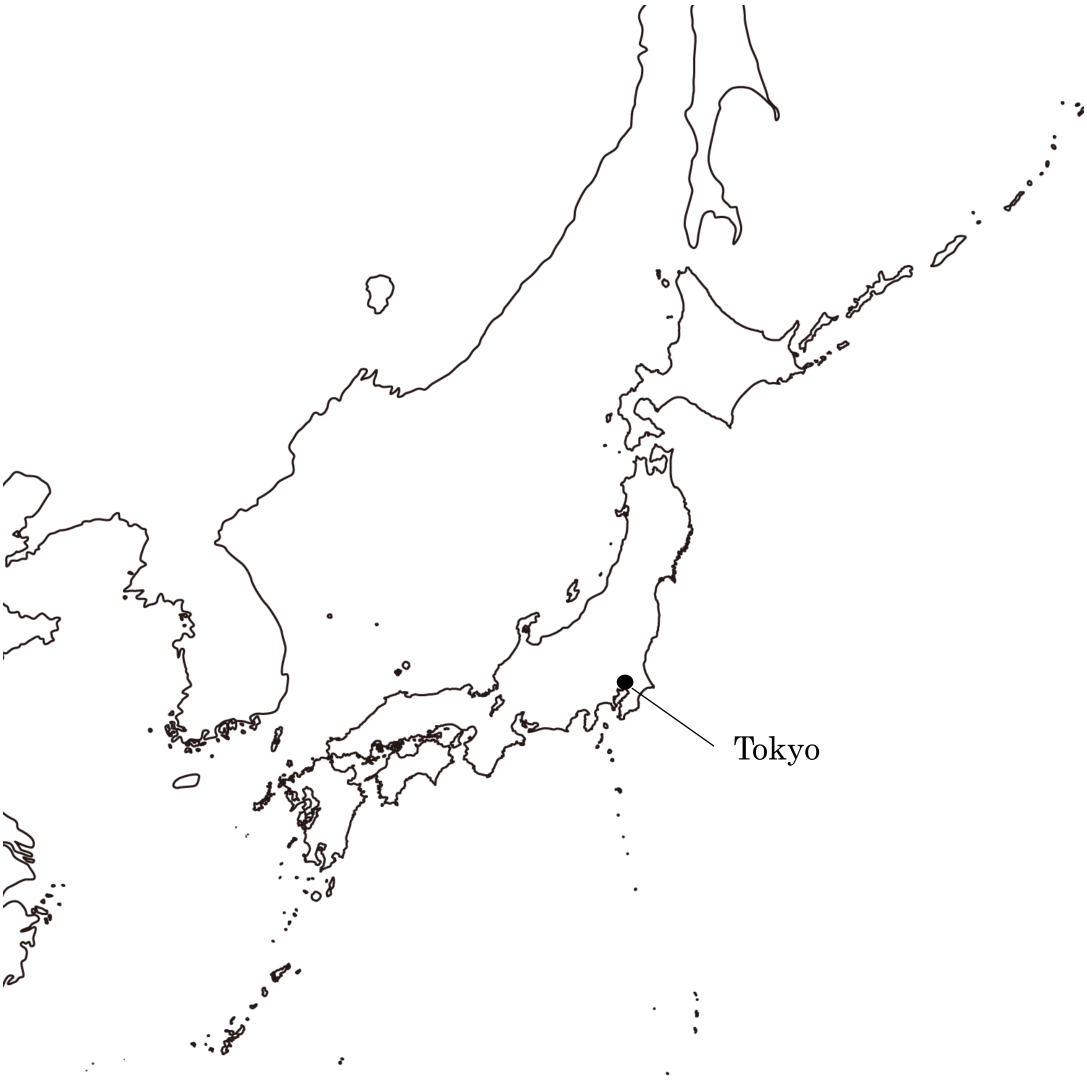


Figure 6. Geographic location of the capital city

Table 9. Characteristics of the capital city

	1990	1995	2000	2005	2011
Geography					
Area(km^2)	2,183.3	2,186.8	2,187.1	2,187.1	2,188.7
Average temperature (Feb. in °C)	7.8	6.5	6.2	6.2	7.0
Average temperature (Aug. in °C)	28.6	29.4	28.3	28.1	27.5
Demography					
Population (million people)	11.7	11.6	11.8	12.2	12.6
Economy					
GRDP (trillion-yen, nominal)	82.4	85.0	93.6	97.8	93.0
Per capita GRDP (million-yen, nominal)	7.0	7.3	8.0	8.0	7.4
Total gross (trillion-yen, nominal)	152.8	157.9	165.7	174.3	163.2
Manufacturing (%)	19.4	16.4	14.1	11.6	5.2
Import (trillion-yen, nominal)	46.0	43.0	41.5	43.4	38.3
Export (trillion-yen, nominal)	62.7	61.0	64.8	69.3	58.9
Energy					
Total final energy consumption (tera J)	698,249	763,190	802,340	789,152	674,083
Per capita energy consumption (mega J)	59,689	65,800	68,282	64,892	53,301
Electricity in final energy consumption (%)	33.4	34.9	36.8	38.1	40.7
Petroleum products in final energy consumption (%)	41.4	38.6	35.5	29.8	25.9
Coal products in final energy consumption (%)	0.31	0.11	0.19	0.03	0.02
Gas products in final energy consumption (%)	24.9	26.3	27.4	30.1	30.9

The population of Tokyo is increasing year by year, and the population of Japan is concentrated in Tokyo. Due to this annual population growth, imports of goods and services are also increasing.

Tokyo has always been the hub of the service industry, and the headquarters of many companies concentrated in Tokyo; thus its GRDP is high.

Under these circumstances, the energy consumption of oil and coal is decreasing, and the amount of energy consumption of electricity and gas is increasing. However, Tokyo's total energy consumption and energy consumption per capita are also decreasing year by year.

3.3 Power supply of the Tokyo Electric Power Company (TEPCO)

Tokyo has received almost all of its electricity supply from TEPCO. TEPCO was affected by the suspension of nuclear power plants in 2003 due to plant inspections, the suspension of the Kashiwazaki-Kariwa Nuclear Power Plant due to the Niigata-Chuetsu-Oki Earthquake in 2007, and the suspension of the Fukushima Daiichi and Daini Nuclear Power Plants due to the Great East Japan Earthquake in 2011.

TEPCO shifted from nuclear power to thermal power generation, and the CO_2 emission intensity (kg- CO_2/kWh) decreased until 2000, but it has increased since 2005 (as shown in Figure 7).

Regarding TEPCO's power generation ratio, the share of nuclear power has dropped to approximately one-third since 2005. On the other hand, power generation from oil has been declining, but thermal power generation from coal and gas has increased markedly since 2005, and instead of nuclear power, the percentage of thermal power has been increasing (as shown in Figure 8).

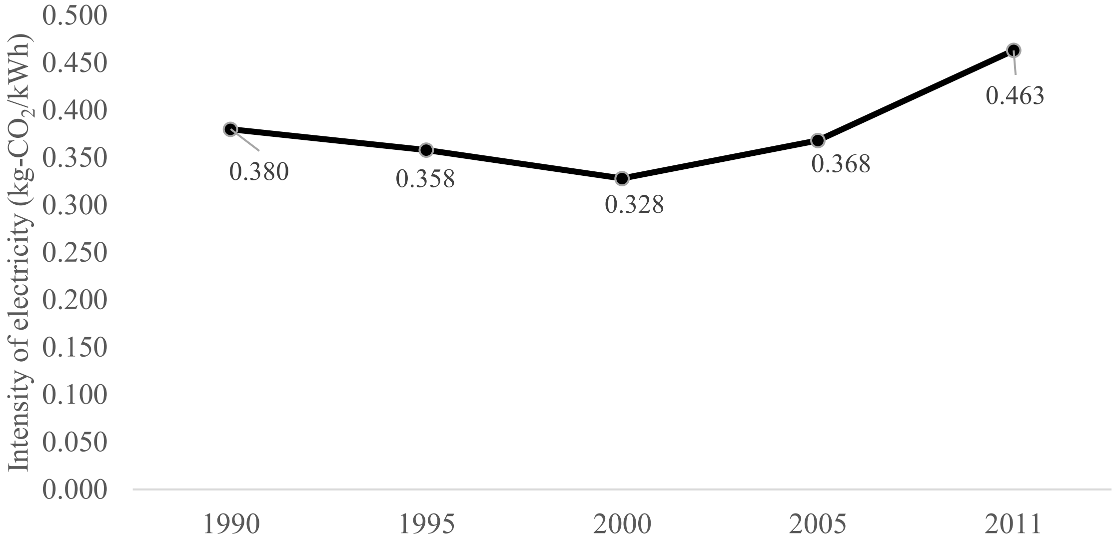


Figure 7. Intensity of electricity of Tokyo Electric Power Company (TEPCO)*

Sources:) * Tokyo Electric Power Company Holdings

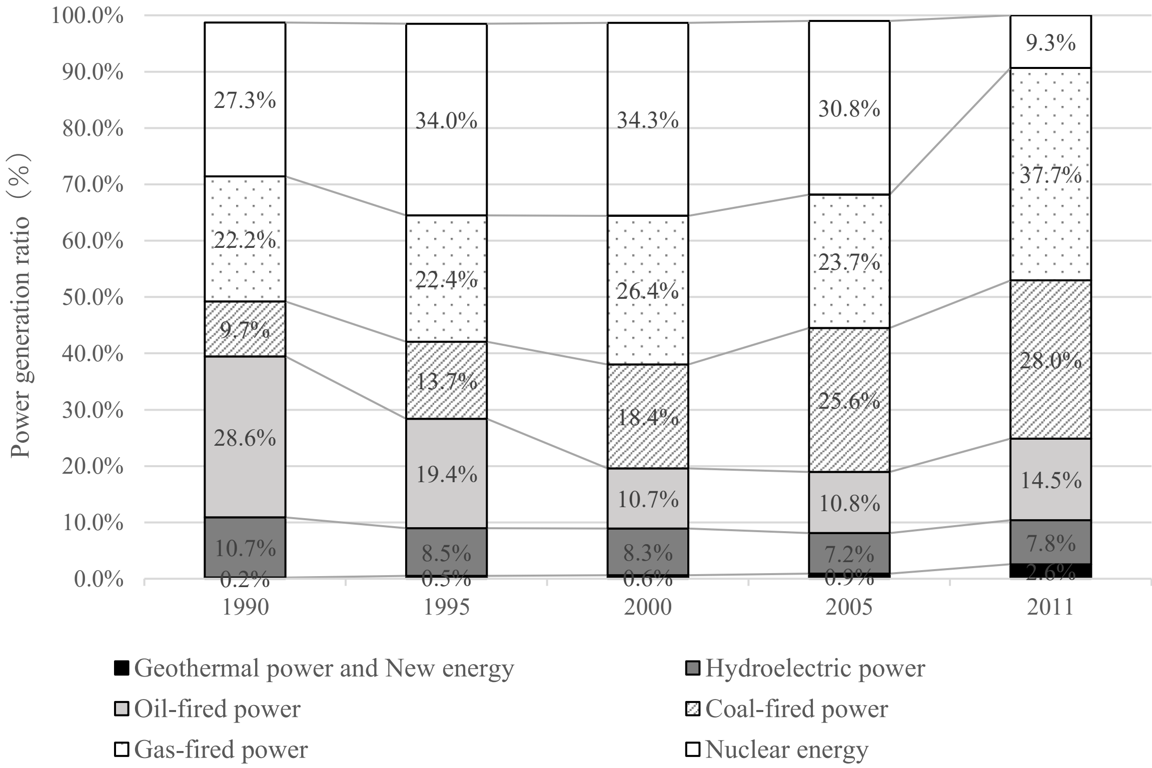


Figure 8. Tokyo Electric Power Company (TEPCO)'s power generation ratio *

Sources:) * Tokyo Electric Power Company Holdings

3.4 Methodology

The multi-regional input-output (MRIO) table published by the TMG is a two-region input-output table that compares "Tokyo" with "Japan outside Tokyo (JOTT)". As presented in Table 10, it clearly shows the interdependence between Tokyo and JOTT in Japan.

Table 10. Multi-regional input-output table of Tokyo

			Intermediate Demand		Final Demand						Gross Output
			Tokyo	JOTT	Tokyo			JOTT			
			1…n	1…n	Consumption	Export	Import	Consumption	Export	Import	
Inter-mediate Input	Tokyo	1…n	X_{ij}^{TT}	X_{ij}^{TO}	F_i^{TT}	EXP_i^{TT}	$-M_i^T$	F_i^{TO}	EXP_i^{TO}	0	X_i^T
	JOTT	1⋯n	X_{ij}^{OT}	X_{ij}^{OO}	F_i^{OT}	EXP_i^{OT}	0	F_i^{OO}	EXP_i^{OO}	$-M_i^O$	X_i^O
Added value			V_j^T	V_j^O							
Gross Input			X_j^T	X_j^O							

Using the MRIO table for Tokyo, we describe the model in which Tokyo and JOTT are mutually carbon-balanced, and the CO2 emissions intensity contained in each of Tokyo and JOTT as follows.

The first is an explanation of the balance of CO2 emissions in Tokyo using column-wise data obtained from a MRIO. The balance of CO2 emissions in Tokyo can be expressed in term of e_n^T , the intensity CO2 emissions of embodied in the products n in Tokyo; e_n^O , the intensity CO2 emissions of embodied in the products n in JOTT : $x_{i,j}^{TT}$, the intermediate input in the Tokyo (including domestic goods and imported goods) ; $x_{i,j}^{OT}$, the intermediate input from JOTT (including domestic goods and imported goods); and D_j^T,the direct CO_2 emissions from sector j :

$$e_j^T X_j^T = e_1^T x_{1,j}^{TT} + e_2^T x_{2,j}^{TT} \cdots + e_n^T x_{n,j}^{TT} + e_1^O x_{1,j}^{OT} + e_2^O x_{2,j}^{OT} \cdots + e_n^O x_{n,j}^{OT} + D_j^T \quad (1)$$

Here, both sides are divided by X_j^T of the total output of sector *j*, which can be rewritten using the input coefficients $a_{i,j}^T$ and $a_{i,j}^O$ for Tokyo and JOTT as follows.

$$e_j^T = e_1^T a_{1,j}^{TT} + e_2^T a_{2,j}^{TT} \cdots + e_n^T a_{n,j}^{TT} + e_1^O a_{1,j}^{OT} + e_2^O a_{2,j}^{OT} \cdots + e_n^O a_{n,j}^{OT} + d_j^T \quad (2)$$

where $a_{i,j}^{TT} = {x_{i,j}^{TT}}/{X_j}$, $a_{i,j}^{OT} = {x_{i,j}^{OT}}/{X_j}$, $d_j^T = {D_j^T}/{X_j}$.

Using matrix and vector notation for sector j=1,…, n, Equation (2) is expressed as:

$$(e_1^T, e_2^T, \ldots, e_n^T) = (e_1^T, e_2^T, \ldots, e_n^T)\begin{bmatrix} a_{1,1}^{TT} & a_{1,2}^{TT} & \ldots & a_{1,j}^{TT} \\ a_{1,2}^{TT} & a_{2,2}^{TT} & \cdots & a_{2,j}^{TT} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n,1}^{TT} & a_{n,2}^{TT} & \ldots & a_{n,j}^{TT} \end{bmatrix} +$$

$$(e_1^O, e_2^O, \ldots, e_n^O)\begin{bmatrix} a_{1,1}^{OT} & a_{1,2}^{OT} & \ldots & a_{1,j}^{OT} \\ a_{1,2}^{OT} & a_{2,2}^{OT} & \cdots & a_{2,j}^{OT} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n,1}^{OT} & a_{n,2}^{OT} & \ldots & a_{n,j}^{OT} \end{bmatrix} + (d_1^T, d_2^T, \ldots, d_n^T) \quad (3)$$

In the noncompetitive transfer and competitive import model, m_i is an import coefficient to the total supply of products *i* and can be specified using the following equation. For imports, it is not easy to distinguish between transfers of goods and services from Japan and imports of goods and services from abroad. In this study, the CO2 emissions of imported goods are calculated assuming that they are manufactured in Japan.

$$m_i = \frac{M_i}{\sum_{j=1}^{n} a_{i,j} X_j + F_i} \quad (4)$$

where M_i is the total value of imported product *i*, $\sum_{j=1}^{n} a_{i,j} X_j$ represents the total intermediate demand for product *i*, and F_i is the final demand for product *i*. To distinguish imported products from domestically produced intermediate products, Equation (3) can be expressed as follows:

$$(e_1^T, e_2^T, \dots, e_n^T) =$$

$$(e_1^T, e_2^T, \dots, e_n^T)\begin{bmatrix} 1-m_i^T & 0 & \dots & 0 \\ 0 & 1-m_i^T & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & 1-m_i^T \end{bmatrix}\begin{bmatrix} a_{1,1}^{TT} & a_{1,2}^{TT} & \dots & a_{1,j}^{TT} \\ a_{1,2}^{TT} & a_{2,2}^{TT} & \cdots & a_{2,j}^{TT} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n,1}^{TT} & a_{n,2}^{TT} & \dots & a_{n,j}^{TT} \end{bmatrix} +$$

$$(e_1^O, e_2^O, \dots, e_n^O)\begin{bmatrix} a_{1,1}^{OT} & a_{1,2}^{OT} & \dots & a_{1,j}^{OT} \\ a_{1,2}^{OT} & a_{2,2}^{OT} & \cdots & a_{2,j}^{OT} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n,1}^{OT} & a_{n,2}^{OT} & \dots & a_{n,j}^{OT} \end{bmatrix} + (d_1^T, d_2^T, \dots, d_n^T) \quad (5)$$

With a vector of intensities of CO_2 emissions embodied by products of Tokyo e_n^T, a diagonal matrix of import coefficients $\hat{M}$, an input coefficient matrix *A*, a vector of direct CO_2 emissions per unit production *d* and the identity matrix *I*, Equation (5) can be expressed as:

$$e_n^T = e_n^T\left(I - \widehat{M}\right)A^{TT} + e_n^O A^{OT} + d^T \quad (6)$$

Solving Equation (6) with respect to e_n^T yields. $[(I - \left(I - \widehat{M}\right)A]^{-1}$,which is called "Leontief's inverse matrix".

$$e_n^T = (e_n^O A^{OT} + d^T)\left[(I - (I - \widehat{M})A^{TT}\right]^{-1}. \quad (7)$$

Then, using row-wise data from an Input-Output table with the given intensity of CO_2 emissions embodied by product *i* of Tokyo, the balance of CO_2 emissions of produced products in sector j can be obtained:

$$e_i^T X_i = e_n^T(1 - m_i^T)\{x_{i,1}^{TT} + x_{i,2}^{TT} + x_{i,3}^{TT} + \dots + x_{i,n}^{TT}\} + e_n^T\{x_{i,1}^{TO} + x_{i,2}^{TO} + x_{i,3}^{TO} + \dots + x_{i,n}^{TO}\}$$

$$+ e_n^T(1 - m_i^T)F_i^{TT} + e_n^T EXP_i^{TT} + e_n^T F_i^{TO} + e_n^T EXP_i^{TO}$$

$$= e_n^T(1 - m_i^T)\sum_{j=1}^{n} x_{i,j}^{TT} + e_n^T \sum_{j=1}^{n} x_{i,j}^{TO}$$

$$+ e_n^T(1 - m_i^T)F_i^{TT} + e_n^T EXP_i^{TT} + e_n^T F_i^{TO} + e_n^T EXP_i^{TO} \quad (8)$$

In equation (8), the treatment of imports is subtracted from intermediate demand x_{ij}^{TT} and the consumption of final demand F_i^{TT}, so imports M_i^T are not subtracted.

Where EXP_i is the export of product i and M_i^T is the import of product i.

Integrating both sides of Equation (9), we obtain:

$$\sum_{i=1}^{n} e_i^T X_i = \sum_{i=1}^{n}\sum_{j=1}^{n} e_n^T (1 - m_i^T) x_{i,j}^{TT} + \sum_{i=1}^{n}\sum_{j=1}^{n} e_n^T x_{i,j}^{TO}$$
$$+ \sum_{i=1}^{n} e_n^T (1 - m_i^T) F_i^{TT} + \sum_{i=1}^{n} e_n^T EXP_i^{TT} + \sum_{i=1}^{n} e_n^T F_i^{TO} + \sum_{i=1}^{n} e_n^T EXP_i^{TO} \qquad (9)$$

Similarly, in reference to Equation (5) using column-wise data from an input-output table:

$$e_j^T X_j = \sum_{i=1}^{n} e_n^T (1 - m_i^T) x_{i,j}^{TT} + \sum_{i=1}^{n} e_n^o x_{i,j}^{OT} + D_j^T \qquad (10)$$

$$\sum_{j=1}^{n} e_j^T X_j = \sum_{j=1}^{n}\sum_{i=1}^{n} e_n^T (1 - m_i^T) x_{1,j}^{TT} + \sum_{j=1}^{n}\sum_{i=1}^{n} e_n^o x_{1,j}^{OT} + \sum_{j=1}^{n} D_j^T \qquad (11)$$

Based on Equations (9) and (11) and considering the control totals principle, which is written as $\sum_{i=1}^{n} e_i^T X_i = \sum_{j=1}^{n} e_j^T X_j$, the following balance is obtained:

$$\sum_{j=1}^{n}\sum_{i=1}^{n} e_n^o x_{i,j}^{OT} + \sum_{j=1}^{n} D_j^T$$
$$= \sum_{i=1}^{n}\sum_{j=1}^{n} e_n^T x_{i,j}^{TO} + \sum_{i=1}^{n} e_n^T (1 - m_i^T) F_i^{TT} + \sum_{i=1}^{n} e_n^T EXP_i^{TT} + \sum_{i=1}^{n} e_n^T F_i^{TO} + \sum_{i=1}^{n} e_n^T EXP_i^{TO} \qquad (12)$$

The upper side of Equation (12) represents the input, total CO_2 emissions associated with production in Tokyo whereas the lower side indicates the final destinations of the CO_2 emissions embodied in the products of Tokyo. Equation (12) captures the balance of CO_2 emissions associated with production processes in Tokyo. However, to construct a more comprehensive balance of the CO_2 emissions associated with city activities, direct CO_2 emissions from the final demand sector that are not related to regional production must be considered.

When the abovementioned CO_2 emissions are added for both the inputs and the distribution of the carbon balance of the economy without altering anything, Equation (13) is obtained:

$$\sum_{j=1}^{n}\sum_{i=1}^{n} e_n^O x_{i,j}^{OT} + \sum_{j=1}^{n} D_j^T + D_F$$
$$= \sum_{i=1}^{n}\sum_{j=1}^{n} e_n^T x_{i,j}^{TO} + \sum_{i=1}^{n} e_n^T (1-m_i^T) F_i^{TT} + \sum_{i=1}^{n} e_n^T EXP_i^{TT} + \sum_{i=1}^{n} e_n^T F_i^{TO}$$
$$+ \sum_{i=1}^{n} e_n^T EXP_i^{TO} + D_F \quad (13)$$

where D_F represents the aggregate direct CO_2 emissions in the final demand sector.

The next is an explanation of the balance of CO2 emissions in JOTT, the balance of CO2 emissions in JOTT can be expressed as Equation (14).

$$e_j^O X_j^O = e_1^T x_{1,j}^{TO} + e_2^T x_{2,j}^{TO} \cdots + e_n^T x_{n,j}^{TO} + e_1^O x_{1,j}^{OO} + e_2^O x_{2,j}^{OO} \cdots + e_n^O x_{n,j}^{OO} + D_j^O \quad (14)$$

Where $x_{i,j}^{TO}$ is the intermediate input from Tokyo (including domestic goods and imported goods) and $x_{i,j}^{OO}$ is the intermediate input in the JOTT (including domestic goods and imported goods).

Here, both sides are divided by X_j^O of the total output of sector j, which can be rewritten using the input coefficients $a_{i,j}^T$ and $a_{i,j}^O$ for Tokyo and JOTT as follows.

$$e_j^T = e_1^T a_{1,j}^{TO} + e_2^T a_{2,j}^{TO} \cdots + e_n^T a_{n,j}^{TO} + e_1^O a_{1,j}^{OO} + e_2^O a_{2,j}^{OO} \cdots + e_n^O a_{n,j}^{OO} + d_j^O \quad (15)$$

where $a_{i,j}^{TO} = x_{i,j}^{TO} / X_j$, $a_{i,j}^{OO} = x_{i,j}^{OO} / X_j$, $d_j^O = D_j^O / X_j$.

Using matrix and vector notation for sector j = 1,…, n, Equation (15) is expressed as:

$$(e_1^O, e_2^O, \dots, e_n^O) = (e_1^T, e_2^T, \dots, e_n^T)\begin{bmatrix} a_{1,1}^{TO} & a_{1,2}^{TO} & \dots & a_{1,j}^{TO} \\ a_{1,2}^{TO} & a_{2,2}^{TO} & \cdots & a_{2,j}^{TO} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n,1}^{TO} & a_{n,2}^{TO} & \dots & a_{n,j}^{TO} \end{bmatrix} +$$

$$(e_1^O, e_2^O, \dots, e_n^O)\begin{bmatrix} a_{1,1}^{OO} & a_{1,2}^{OO} & \dots & a_{1,j}^{OO} \\ a_{1,2}^{OO} & a_{2,2}^{OO} & \cdots & a_{2,j}^{OO} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n,1}^{OO} & a_{n,2}^{OO} & \dots & a_{n,j}^{OO} \end{bmatrix} + (d_1^O, d_2^O, \dots, d_n^O) \quad (16)$$

As in the case of Tokyo, we assume that the imported product is manufactured in Japan, Equation (16) can be expressed as follows:

$$(e_1^O, e_2^O, \dots, e_n^O) = (e_1^T, e_2^T, \dots, e_n^T)\begin{bmatrix} a_{1,1}^{TO} & a_{1,2}^{TO} & \dots & a_{1,j}^{TO} \\ a_{1,2}^{TO} & a_{2,2}^{TO} & \cdots & a_{2,j}^{TO} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n,1}^{TO} & a_{n,2}^{TO} & \dots & a_{n,j}^{TO} \end{bmatrix} +$$

$$(e_1^O, e_2^O, \dots, e_n^O)\begin{bmatrix} 1 - m_i^O & 0 & \dots & 0 \\ 0 & 1 - m_i^O & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & 1 - m_i^O \end{bmatrix}\begin{bmatrix} a_{1,1}^{OO} & a_{1,2}^{OO} & \dots & a_{1,j}^{OO} \\ a_{1,2}^{OO} & a_{2,2}^{OO} & \cdots & a_{2,j}^{OO} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n,1}^{OO} & a_{n,2}^{OO} & \dots & a_{n,j}^{OO} \end{bmatrix} +$$

$$(d_1^O, d_2^O, \dots, d_n^O) \quad (17)$$

With a vector of intensities of CO_2 emissions embodied by products of JOTT e_n^O, a diagonal matrix of import coefficients $\hat{M}$, an input coefficient matrix *A*, a vector of direct CO_2 emissions per unit production d^O and the identity matrix *I*, Equation (17) can be expressed as:

$$e_n^O = e_n^T A^{TO} + e_n^O (I - \widehat{M}) A^{OO} + d^O. \quad (18)$$

Solving Equation (18) with respect to e_n^T yields.

$$e_n^O = (e_n^T A^{TO} + d^O) \left[(I - (I - \widehat{M}) A^{OO}\right]^{-1}. \quad (19)$$

Then, using row-wise data from an Input-Output table with the given intensity of CO_2 emissions embodied by product *i* of JOTT, the balance of CO_2 emissions of domestically produced products in sector *j* can be obtained:

$$
\begin{aligned}
e_i^O X_i &= e_n^O\{x_{i,1}^{OT} + x_{i,2}^{OT} + x_{i,3}^{OT} + \cdots + x_{i,n}^{OT}\} + e_n^O(1 - m_i^O)\{x_{i,1}^{OO} + x_{i,2}^{OO} + x_{i,3}^{OO} + \cdots + x_{i,n}^{OO}\} \\
&\quad + e_n^O F_i^{OT} + e_n^O EXP_i^{OT} + e_n^O(1 - m_i^O)F_i^{OO} + e_n^O EXP_i^{OO} \\
&= e_n^O \sum_{j=1}^{n} x_{i,j}^{OT} + e_n^O(1 - m_i^O)\sum_{j=1}^{n} x_{i,j}^{OO} \\
&\quad + e_n^O F_i^{OT} + e_n^O EXP_i^{OT} + e_n^O(1 - m_i^O)F_i^{OO} + e_n^O EXP_i^{OO} \qquad (20)
\end{aligned}
$$

where EXP_i is the export of product *i* and M_i^O is the import of product *i*. Integrating both sides of Equation (20), we obtain:

$$
\begin{aligned}
\sum_{i=1}^{n} e_i^O X_i &= \sum_{i=1}^{n}\sum_{j=1}^{n} e_n^O x_{i,j}^{OT} + \sum_{i=1}^{n}\sum_{j=1}^{n} e_n^O(1 - m_i^O)x_{i,j}^{OO} \\
&\quad + \sum_{i=1}^{n} e_n^O F_i^{OT} + \sum_{i=1}^{n} e_n^O EXP_i^{OT} + \sum_{i=1}^{n} e_n^O(1 - m_i^O)F_i^{OO} + \sum_{i=1}^{n} e_n^O EXP_i^{OO} \qquad (21)
\end{aligned}
$$

Similarly, in reference to Equation (17) using column-wise data from an input-output table:

$$
e_j^O X_j = \sum_{i=1}^{n} e_n^T x_{i,j}^{TO} + \sum_{i=1}^{n} e_n^o\left(1 - m_i^O\right)x_{i,j}^{OO} + D_j^O \qquad (22)
$$

$$
\sum_{j=1}^{n} e_j^O X_j = \sum_{j=1}^{n}\sum_{i=1}^{n} e_n^T x_{i,j}^{TO} + \sum_{j=1}^{n}\sum_{i=1}^{n} e_n^o\left(1 - m_i^O\right)x_{i,j}^{OO} + \sum_{j=1}^{n} D_j^O \qquad (23)
$$

Based on Equations (21) and (23 and considering the control totals principle, which is written as $\sum_{i=1}^{n} e_i^O X_i = \sum_{j=1}^{n} e_j^O X_j$,the following balance is obtained: D_j^O

$$\sum_{j=1}^{n}\sum_{i=1}^{n} e_n^T x_{i,j}^{TO} + \sum_{i=1}^{n} D_j^O$$

$$= \sum_{i=1}^{n}\sum_{j=1}^{n} e_n^O x_{i,j}^{OT} + \sum_{i=1}^{n} e_n^O F_i^{OT} + \sum_{i=1}^{n} e_n^O EXP_i^{OT} + \sum_{i=1}^{n} e_n^O (1 - m_1) F_i^{OO} + \sum_{i=1}^{n} e_n^O EXP_i^{OO} \quad (24)$$

The upper side of Equation (24) represents the input, total CO_2 emissions associated with production in JOTT whereas the lower side indicates the final destinations of the CO_2 emissions embodied in the products of JOTT. Equation (24) captures the balance of CO_2 emissions associated with production processes in JOTT. However, to construct a more comprehensive balance of the CO_2 emissions associated with city activities, direct CO_2 emissions from the final demand sector that are not related to regional production must be considered.

When the abovementioned CO_2 emissions are added for both the inputs and the distribution of the carbon balance of the economy without altering anything, Equation (25) is obtained:

$$\sum_{j=1}^{n}\sum_{i=1}^{n} e_n^T x_{i,j}^{TO} + \sum_{i=1}^{n} D_j^O + D_F$$

$$= \sum_{i=1}^{n}\sum_{j=1}^{n} e_n^O x_{i,j}^{OT} + \sum_{i=1}^{n} e_n^O F_i^{OT} + \sum_{i=1}^{n} e_n^O EXP_i^{OT} + \sum_{i=1}^{n} e_n^O (1 - m_1) F_i^{OO}$$

$$+ \sum_{i=1}^{n} e_n^O EXP_i^{OO} + D_F \quad (25)$$

where D_F represents the aggregate direct CO_2 emissions in the final demand sector.

3.5 Boundary setting and model application

In order to take imports into account, it is necessary to have an input-output table for foreign countries. Due to data limitations, it is not possible to easily distinguish between the transfers of goods and services from domestic and the imports of goods and services from foreign country. In this study, imports are taken into account, but the CO_2 emissions of imported goods are calculated assuming that they are manufactured in Japan.

3.6 Data

There are two primary sources of data used in the empirical analysis in this study: energy balance tables and input-output tables.

The TMG has prepared an original inter-region input-output table between Tokyo and JOTT (as shown in Table 11).Energy input-output analysis is usually constrained by the availability of data on energy consumption by sector. Since the energy table of Tokyo is not available to the public, we asked the Bureau of Statistics of TMG to obtain the data. The energy data available are summarized in Table 12, and energy balance tables that contain the energy transformation sector are available in Japan but not available for Tokyo. The gap in information on the energy transformation sector in Tokyo can be filled by additional individual statistical reports on plant- or firm-level information for the power and gas industries. The energy and CO_2 for the empirical analysis were estimated using these energy balance tables and based on the CO_2 emission intensity of the Ministry of the Environment for each year, which is same as data of the Center for Global Environmental Research of National Institute for Environmental Studies in Japan, except for electricity in Tokyo. For Tokyo's electricity, we used the CO_2 intensity for each fiscal year from the and TMG's " Final Energy Consumption and Greenhouse Gas Emissions in Tokyo”.

JOTT's energy balance table is obtained by subtracting the Tokyo Metropolitan Government's energy balance table from the national energy balance table. For the national energy balance table, we used the environmental impact unit data (3EID) from the Center for Global Environmental Research at the National Institute for Environmental Studies in Japan. This data is more detailed than the national energy balance (Agency for Natural

Resources and Energy, Ministry of Economy, Trade and Industry) and has data from 1990, which is useful for the analysis in this chapter.

Considering the availability of data on sectoral energy consumption, the common unified sector classification of input-output tables for coherent empirical analysis in Tokyo is set (as shown in Table 13). The original input-output tables are processed and aggregated to forty unified sectors.

Table 11. Sectors of endogenous transactions in original input-output tables of Tokyo

	1990	1995	2000	2005	2011
Tokyo	280	280	281	280	191
JOTT	268	268	269	269	191

Table 12. Energy balance table calculated for various statistics

	Japan					Tokyo
Sources	Embodied Energy and Emission Intensity Data for Japan Using Input-Output Tables *					1) Energy balance table of Tokyo** 2) Statistical Tables of Electrical Power (Overview of Electricity Supply) 3) Statistical Tables of Gas (Annual report of gas business)
	1990	1995	2000	2005	2011	
Agriculture	14 sectors	14 sectors	13 sectors	27 sectors	27 sectors	Single sector
Mining	8 sectors	6 sectors	6 sectors	6 sectors	5 sectors	Single sector
Manufacturing	109 sectors	109 sectors	110 sectors	244 sectors	238 sectors	19 sectors; oil and coal products are in one sector, chemical is a single sector.
Energy	5 sectors	5 sectors	5 sectors	9 sectors	9 sectors	Power plant data are taken from the Outline of Electricity Demand and Supply, and firm-level data for the gas industry are taken from the Annual Statistical Report of the Gas Industry
Construction	5 sectors	5 sectors	5 sectors	12 sectors	12 sectors	Single sector
Transportation	10 sectors	10 sectors	10 sectors	12 sectors	12 sectors	4 sectors
Service and others	36 sectors	37 sectors	39 sectors	93 sectors	92 sectors	9 sectors

Sources: *) The Center for Global Environmental Research, National Institute for Environmental Studies National Institute for Environmental Studies , Japan,

**) Environmental Bureau, TMG (Tokyo Metropolitan Government)

Table 13. Unified sector classification for Tokyo

Sector		Industrial classification
Nonmanufacturing	1	Agriculture
	2	Mining (except oil and coal)
	3	Coal mining
	4	Oil and natural gas mining
Manufacturing	5	Food
	6	Beverages, tobacco and feed
	7	Textiles
	8	Apparel and other textile products
	9	Lumber and wood products
	10	Furniture and fixtures
	11	Pulp and paper
	12	Publishing and printing
	13	Chemical products
	14	Petroleum products
	15	Coal products
	16	Plastic products
	17	Rubber products
	18	Tanned leather and leather products
	19	ceramics, stone and clay products
	20	Iron and steel
	21	Nonferrous metals
	22	Metal products
Manufacturing	23	General machinery
	24	Electric machinery
	25	Transportation equipment
	26	Precision machinery
	27	Other manufacturing products
Construction	28	Construction
	29	Electricity
	30	Gas
	31	Heat supply
	32	Water supply and waste disposal
Services	33	Commerce
	34	Finance and insurance
	35	Real estate
	36	Automobiles
	37	Railways
	38	Ships
	39	Airplanes
	40	Other transportation
	41	Communication and broadcasting
	42	Public services
	43	Education and research, medical, health, and social security services
	44	Services

3.7 Results

3.7.1 CO_2 emissions based on the system boundaries approach

As shown in Table 14 and Table 15, the four system boundaries approach is used to examine and compare Tokyo's CO_2 emissions.

Compared to the emissions under SB-1, which are the direct CO_2 emissions used by the IPCC, the emissions under SB-2, which include electricity transferred to direct CO_2 emissions, are 2.04 to 2.68 times larger, and the embodied CO_2 emissions from electricity account for more than half of emissions under SB-2. The CO_2 emissions under SB-3, which indicates a carbon footprint, are 4.61 to 5.30 times larger than those under SB-1, and it is found that the economy of Tokyo is active and large.

Additionally, the emissions under SB-4, which are consumption-based emissions, are 2.72 to 3.38 times larger than those under SB-1. This result means that the embodied CO_2 emissions of goods and services imported from JOTT account for a large proportion of the emissions under SB-4.

Incidentally, the emissions under SB-4 are approximately 1.23 to 1.48 times as large as those under SB-2, which is the system boundary generally used by local governments (as shown in Table 16).

Next, we analyze the long-term changes in total CO_2 emissions for each system boundary (as shown in Table 17).

Comparing total CO_2 emissions with 1990, we see that the emissions under SB-1 increased until 2005 and decreased in 2011, and those under SB-2 increased in all fiscal years and those emissions under SB-3 decreased in all fiscal years. In addition, the emissions under SB-4 are decreased until 2005 but increased in 2011. Comparing per capita CO_2 emissions with 1990, we see that the emissions of system boundaries except for SB-4 show the same trend as the change in total CO_2 emissions. For the emissions under SB-4 decreased in all fiscal years.

This result shows that in the long-term SB-2 emissions have been increasing and SB-4 emissions have remained almost unchanged. we assumed that emissions under SB-2 would increase due to the nuclear accident and that emissions under SB-4 would also increase, but as it turned out, emissions under SB-4, which are consumption-based emissions, were stable.

Table 14. CO_2 emissions of Tokyo estimated using different accounting methods

<Total CO_2 emissions> Unit: million t-CO_2

	1990	1995	2000	2005	2011
SB-1	33.7	35.8	35.4	36.9	31.1
SB-2	69.3	75.8	72.3	81.2	83.5
SB-3	178.7	170.2	163.5	170.0	163.3
SB-4	102.3	98.3	97.1	100.3	105.1
Publication by the TMG	54.4	58.2	58.9	61.7	61.4

<Per capita CO_2 emissions> Unit: t-CO_2

	1990	1995	2000	2005	2011
SB-1	2.9	3.1	3.0	3.0	2.5
SB-2	5.9	6.5	6.2	6.7	6.6
SB-3	15.3	14.7	13.9	14.0	12.9
SB-4	8.7	8.5	8.3	8.2	8.3
Publication by the TMG	4.7	5.0	5.0	5.2	4.9

Table 15. Ratio of CO_2 emissions under each carbon accounting method compared to SB-1

	1990	1995	2000	2005	2011
SB-2/SB-1	2.06	2.12	2.04	2.20	2.68
SB-3/SB-1	5.30	4.76	4.61	4.61	5.25
SB-4/SB-1	3.03	2.75	2.74	2.72	3.38

Table 16. Ratio of CO_2 emissions under SB-4 compared to SB-2

	1990	1995	2000	2005	2011
SB-4/SB-2	1.48	1.30	1.34	1.23	1.26

Table 17. Ratio of CO_2 emissions under each carbon accounting method compared to 1990

<Total CO_2 emissions>

	1995/1990	2000/1990	2005/1990	2011/1990
SB-1	1.06	1.05	1.09	0.92
SB-2	1.09	1.04	1.17	1.20
SB-3	0.95	0.91	0.95	0.91
SB-4	0.96	0.95	0.98	1.03

<Per capita CO_2 emissions>

	1995/1990	2000/1990	2005/1990	2011/1990
SB-1	1.07	1.05	1.05	0.85
SB-2	1.10	1.04	1.13	1.11
SB-3	0.96	0.91	0.92	0.85
SB-4	0.97	0.95	0.94	0.95

We now determine why the emissions under SB-4, which are per capita consumption-based emissions, remain stable and how power supply factors are related after the suspension of power plants. SB-4 equals the sum of Scope 1 and Scope 3 minus Scope 4. Scope 1 refers to direct CO_2 emissions: SB-1. Scope 3 refers to all other CO_2

emissions embodied in all commodities, including electricity, supplied to a city from outside its administrative boundaries, and Scope 4 accounts for all emissions except for those embodied in product exports.

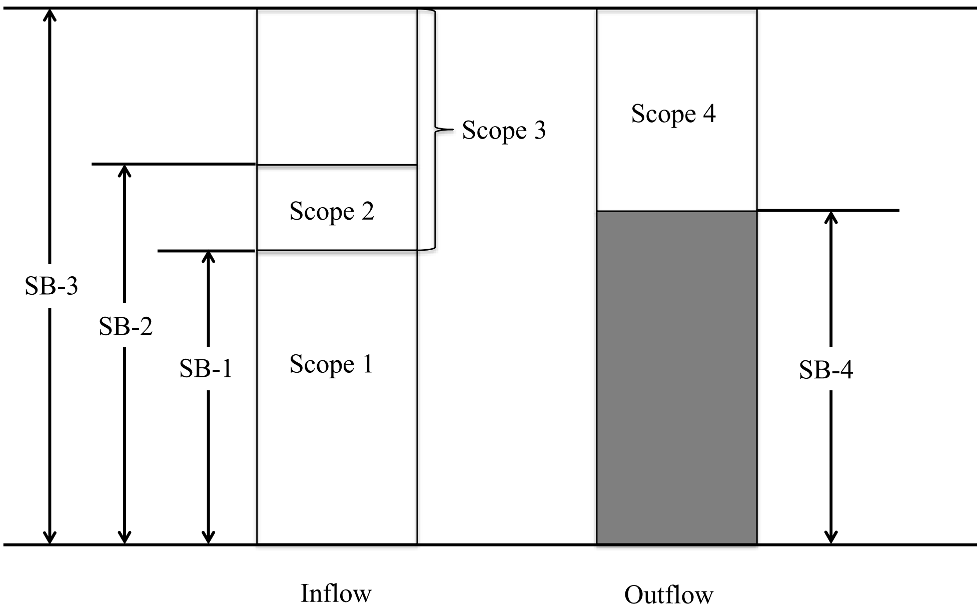


Figure 2 (repost from page11). Scope and system boundaries (SBs) of this study

As shown in Table 18 and Table 19, the ratio of Scope 3 to Scope 4 is the same, although total CO_2 emissions and per capita CO_2 emissions have decreased slightly compared to 1990.

The ratio of CO_2 emissions of goods and services imported from JOTT to those exported to JOTT has not changed during the study period, and as a result SB-4 has not changed. However, while Scope 3, which represents imports of goods and services from JOTT, has decreased, the ratio of Scope 2, which represents imports of electricity out of Scope 3, has increased.

Table 18. CO_2 emissions of Tokyo using different Scopes

<Total CO_2 emissions> Unit: million t-CO_2

	1990	1995	2000	2005	2011
Scope 1	33.7	35.8	35.4	36.9	31.1
Scope 2	35.6	40.0	36.9	44.4	52.4
Scope 3	145.0	134.4	128.0	133.2	132.2
Scope 4	76.4	71.9	66.3	69.8	58.2

<Per capita CO_2 emissions> Unit: t-CO_2

	1990	1995	2000	2005	2011
Scope 1	2.9	3.1	3.0	3.0	2.5
Scope 2	3.0	3.5	3.1	3.6	4.1
Scope 3	12.4	11.6	10.9	11.0	10.5
Scope 4	6.5	6.2	5.6	5.7	4.6

Table 19. Ratio of CO_2 emissions in each scope compared to 1990

<Total CO_2 emissions>

	1995/1990	2000/1990	2005/1990	2011/1990
Scope 1	1.06	1.05	1.09	0.92
Scope 2	1.12	1.04	1.25	1.47
Scope 3	0.93	0.88	0.92	0.91
Scope 4	0.94	0.87	0.91	0.76

<Per capita CO_2 emissions>

	1995/1990	2000/1990	2005/1990	2011/1990
Scope 1	1.07	1.05	1.05	0.85
Scope 2	1.13	1.03	1.20	1.36
Scope 3	0.94	0.88	0.88	0.84
Scope 4	0.95	0.86	0.88	0.70

3.7.2 Changes in the power supply and demand of Tokyo

To analyze the change in Scope 2 (CO_2 emissions included in electricity supplied from outside the city), which increased from 1990 to 2011, we further analyzed the change in CO_2 emission intensity and the amount of electricity transferred from JOTT. With e (million t-CO_2/Yen), CO_2 emission intensity and E (million yen), the amount of electricity transferred as electricity consumption; SCOPE2 can be expressed as follows.

$$CO_2(Scope2) = eE$$

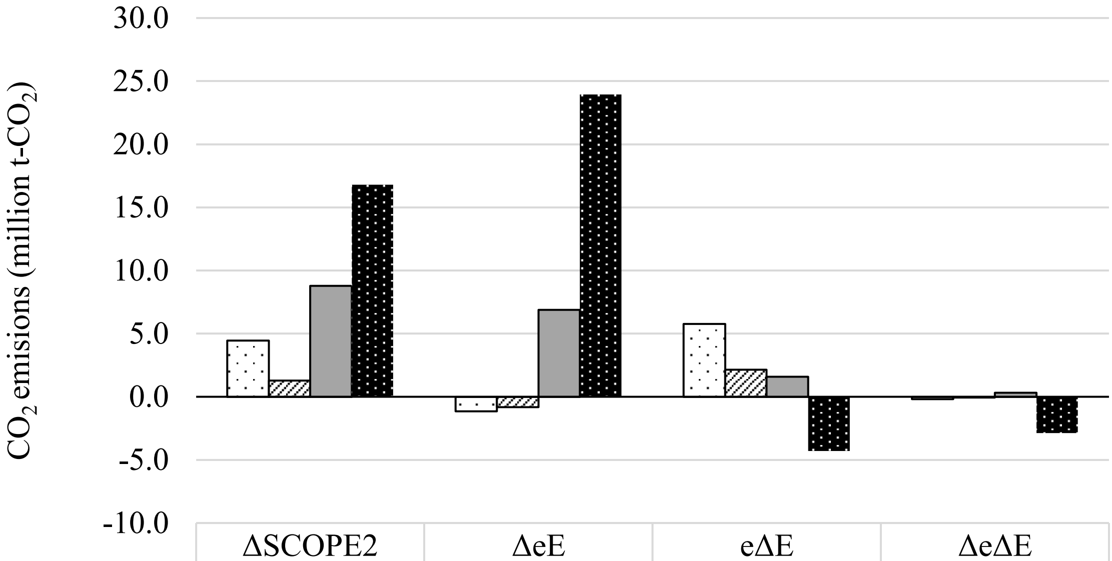
$$\Delta CO_2(Scope2) = \Delta eE + e\Delta E + \Delta e\Delta E$$

As shown in Figure 9, electricity consumption increased until 2005 but decreased in 2011. In addition, the CO_2 emission intensity was small until 2000 but started to increase from 2005 because one nuclear power plant was suspended in 2005, and it became noticeably larger in 2011 because two nuclear power plants were suspended and shifted to thermal power.

In 2011, electricity consumption decreased due to the impact of the suspension of nuclear power plants, but Scope 2 became larger due to the increase in the CO_2 emission intensity.

Thus, the impact of the increase in CO_2 emission intensity was more pronounced in 2005 and 2011 when the nuclear power plants were suspended. This result means that even if electricity consumption is reduced, emissions will increase as a result of the use of electricity with a large CO_2 emission intensity. The reason why SB-4 in Tokyo is not decreasing is related to the fact that embodied CO_2 emissions of electricity is not decreasing.

As electric power companies other than TEPCO find themselves in a similar position, if the consumption structure does not change in regional cities as well, the embodied CO_2 emissions of electricity will increase due to an increase in the CO_2 emission intensity from electricity.



	ΔSCOPE2	ΔeE	eΔE	ΔeΔE
1995/1990	4.4	-1.1	5.8	-0.2
2000/1990	1.3	-0.8	2.1	-0.0
2005/1990	8.8	6.9	1.6	0.3
2011/ 1990	16.8	24.0	-4.3	-2.9

Figure 9. Relationship between the energy consumption of electricity and Scope 2 in Tokyo

3.8 Summary of findings

The three major findings of this empirical study are summarized below.

1) The consumption-based emissions (SB-4) of Tokyo were 2.72 to 3.38 times larger than the direct CO_2 emissions (SB-1). If we consider consumption-based emissions instead of production-based emissions, we see that Tokyo is responsible for approximately twice as many emissions. Incidentally, the emissions under SB-4 were approximately 1.23 to 1.48 times as large as those under SB-2, which is the system boundary generally used by local governments.

2) SB-4 emissions, which are consumption-based CO_2 emissions, were expected to increase after the electricity supply shock, but total emissions and per capita CO_2 emissions have remained stable.

3) CO_2 emissions embodied in externally supplied electricity (Scope 2) have continued to increase between 1990 and 2011. In particular, in 2005 and 2011, when there were electricity shocks, the CO_2 emission intensity from electricity became very high, affecting Scope 2 and increasing SB-2. One of reasons why Tokyo's SB-4 has not decreased is that the embodied CO_2 emissions of electricity have not decreased.

Chapter 4

Verification of carbon mitigation responsibility calculated with single-regional and multi-regional input-output tables

4.1 Objectives

As shown in Chapter 1, there are many studies that use input-output tables to calculate indirect emissions. In particular, the MRIO table shows the amount of CO_2 emissions induced by the consumption of goods and services and allows us to understand the spillover effects of CO_2 emissions between industries and regions. However, the SRIO table is used for the six largest cities in Japan because they do not have the MRIO table in Chapter 2, and the MRIO table is used for Tokyo to analyze the carbon mitigation responsibility of cities in Chapter 3.

In their assessment of Tokyo's CO_2 emissions, Long et al. (2020b) found that there is a gap between the SRIO and MRIO tables and that the difference in CO_2 emissions due to final demand in Tokyo is quite large. In their study, the energy balance table is converted from the Tokyo input-output table by the calorific value and emission intensity per energy source of the Agency for Natural Resources and Energy. In this way, the figures deviate from the actual energy consumption, making it difficult to estimate the exact amount of energy due to differences in product prices and other factors in different regions. In particular, the amount of energy in Tokyo is likely to be large because it includes the headquarters function, which has a large production value.

Therefore, it is important to understand the difference between Tokyo's SRIO and

MRIO tables by calculating with input-output tables and the energy balance tables in this paper. Understanding this difference, we compare the consumption-based emissions (SB-4) based on the SRIO and MRIO tables to verify the carbon mitigation responsibility of cities.

4.2 Methodology and data

The analysis using SRIO tables was conducted based on the methodology in Chapter 2 (see 2.3), and the analysis using MRIO tables was conducted based on the methodology in Chapter 3 (see 3.4).

For the input-output tables in this chapter, we used the SRIO and MRIO tables prepared and published by the Tokyo Metropolitan Government. For the national SRIOs, the MRIO Tokyo and its regions were added together to create the input-output table. We also processed these input-output tables and aggregated them into 44 unified sectors.

In addition, as in Chapter 3, we used the energy balance tables for Tokyo and Japan and classified them into the 44 common sectors of the Input-Output table (as shown in Table 13).

4.3 Results

To evaluate the difference in CO_2 emissions between SRIO and MRIO, SB-2, SB-3, and SB-4 at the system boundary were calculated using SRIO and compared with the MRIO values calculated in Chapter 3. The direct emissions (SB-1) were omitted since they are the same.

As shown in Table 20, SB-2 calculated by SRIO and MRIO were almost the same. SRIO used the CO_2 intensity of electricity in Japan, while MRIO was calculated by the embodied CO_2 intensity of electricity from other regions, but there was no significant difference in the intensity of both, because electricity generation in Tokyo is extremely small.

However, as shown in Table 21, SB-3 of MRIO is smaller than the calculated value of SRIO.SRIO uses embodied CO_2 intensity in Japan for imports and transfers in the goods and services sector. MRIO, like SRIO, does not distinguish between imports and transfers, but since the intermediate input in the Tokyo region includes domestic goods and imported goods, they are calculated using carbon balance by the CO_2 emission intensity of both Tokyo and JOTT. Although there is not a large gap between the value for embodied CO_2 emission intensity values of Japan and JOTT, the value of the MRIO in Scope 3 is smaller than that of the SRIO because Tokyo's CO_2 emission intensity is smaller than those of JOTT.

As for SB-4, as shown in Table 22, SRIO seems to be smaller than MRIO in 1990 and 1995, and larger than MRIO after 2000. Therefore, when we examine the changes in Scope 3 and Scope 4 in Table 23, SRIO is larger than MRIO in both cases. This is because

Scope 3 is the same as SB-3, and for Scope 4, This is because when raw materials are transferred from JOTT and exported from Tokyo as products, that is, when they are transferred from JOTT to Tokyo as intermediate inputs and exported from Tokyo as final demand, they are included in transfers and exports of Tokyo in the case of SRIO, but not in exports of Tokyo in the case of MRIO. The difference between the trend up to 1995 and the trend after 2000 is due to the difference in the value of Scope 3 minus Scope 4.

In addition, to establish the long-term changes in Chapter 4, comparing SRIO and MRIO, we can see that both total emissions and per capita CO_2 emissions remain almost the same, although the difference between SRIO and MRIO is larger in 2011 (as shown in Figure 10).

This result shows that SB-4 does not change the long-term trend of change for both SRIO and MRIO.

Table 20. Amount and ratio of CO_2 emissions calculated by SRIO and MRIO in SB-2

	1990	1995	2000	2005	2011
SRIO (Million t-CO_2)	69.1	75.6	72.3	81.0	82.9
MRIO(Million t-CO_2)	69.3	75.8	72.3	81.2	83.5
SRIO/MRIO	1.00	1.00	1.00	1.00	0.99

Table 21. Amount and ratio of CO_2 emissions calculated by SRIO and MRIO in SB-3

	1990	1995	2000	2005	2011
SRIO (Million t-CO_2)	191.7	183.6	181.6	191.4	178.4
MRIO(Million t-CO_2)	178.7	170.2	163.5	170.0	163.3
SRIO/MRIO	1.07	1.08	1.11	1.13	1.09

Table 22. Amount and ratio of CO_2 emissions calculated by SRIO and MRIO in SB-4

	1990	1995	2000	2005	2011
SRIO (Million t-CO_2)	97.9	96.0	98.3	102.5	113.6
MRIO(Million t-CO_2)	102.3	98.3	97.1	100.3	105.1
SRIO/MRIO	0.96	0.98	1.01	1.02	1.08

Table 23. Difference between Scope 3 and Scope 4 by MRIO and SRIO

<Scope3>

	1990	1995	2000	2005	2011
SRIO (Million t-CO_2)	157.9	147.9	146.1	154.5	147.3
MRIO(Million t-CO_2)	145.0	134.4	128.0	133.2	132.2

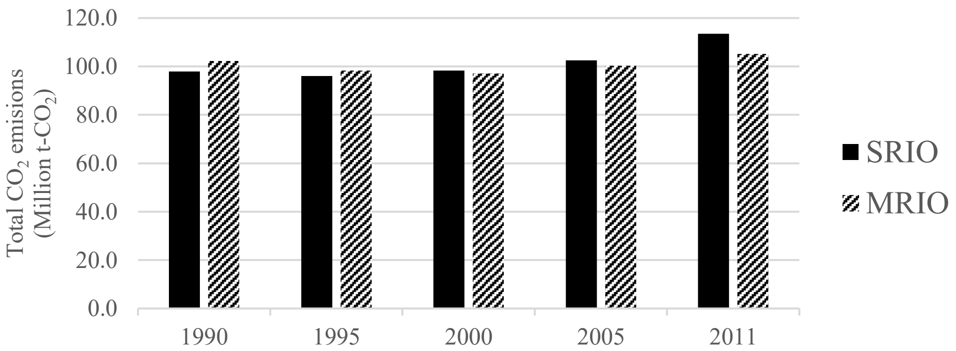
<Scope4>

	1990	1995	2000	2005	2011
SRIO (Million t-CO_2)	93.8	87.6	83.3	88.9	64.8
MRIO(Million t-CO_2)	76.4	71.9	66.3	69.8	58.2

<Scope3 minus Scope4>

	1990	1995	2000	2005	2011
SRIO (Million t-CO_2)	12.9	13.5	18.1	21.3	15.1
MRIO(Million t-CO_2)	17.4	15.7	17	19.1	6.6
SRIO minus MRIO(Million t-CO_2)	-4.5	-2.2	1.1	2.2	8.5

<Total CO_2 emissions>



<Per capita CO_2 emissions>

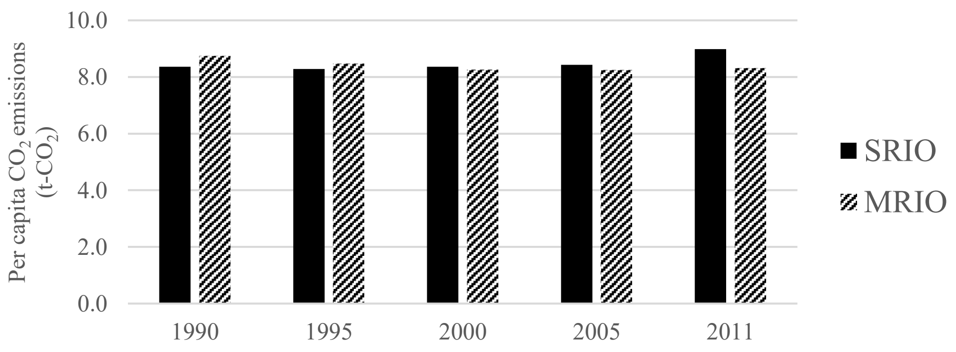


Figure 10. Ratio of consumption-based emissions (SB-4) in each year compared to 1990

Chapter 5

Conclusions and policy implications

Cities are complex systems because of their intensive internal metabolism and their vigorous cross-boundary linkages with respect to material goods, ecosystem services, trade, urban governance, and other matters. Cities' responsibility for CO_2 emissions and mitigation can be greatly extended because the footprint of their activities extends far beyond their boundaries. Cities draw resources and ecological services from outside of their boundaries because they are characterized by large populations in small physical spaces and high-intensity activities. In particular, the intensive consumption activities responsible for upstream emissions are key defining characteristics of cities.

This study intends to allocate the carbon mitigation responsibility from energy by capturing the embodied carbon emissions from resources and ecological services. Therefore, special treatment of energy commodities is required since they contain both energy values leading to direct CO_2 emissions and indirect and embodied carbon emissions.

Thus, we used the four system boundaries as follows: SB-1 indicates direct CO_2 emissions, SB-2 equals the sum of direct emissions and CO_2 emissions embodied in electricity, and SB-3 equals the sum of direct emissions and all other CO_2 emissions embodied in all commodities, which indicates a carbon footprint. Finally, system boundary 4 (SB-4) accounts for all emissions except for those embodied in product exports; it indicates consumption-based emissions. SB-4 exempts the export side from responsibility and places all other responsibility on the final consumer side, stipulating that the final consumer of goods and services is responsible for all CO_2 generated in production and distribution. For this reason, we define SB-4 as the carbon mitigation responsibility of cities that have cross-boundary linkages with respect to material goods, ecosystem services, trade, etc.

Most Japanese cities employ emission inventories obtained using SB-2 to set targets and goals for climate action plans. Using this system boundary, industrial cities, which have many manufacturing industries creating products that are not to consumed within the industrial cities, have CO_2 emissions consumption demands of consuming cities. Service cities, which have many service industries, consume more goods than industrial cities, but they do not have more CO_2 emissions than industrial cities.

Cities are also shifting their industrial structures toward those of consuming cities. In this way, the CO_2 emissions of cities are estimated to be low, and climate action plans are assessed to be successful in achieving their climate change mitigation targets. Therefore, it is important to consider CO_2 emissions not only in terms of production but also in terms of consumption in policy making and evaluation.

This issue can be addressed by comparing the system boundary from four different perspectives: SB-1 shows the direct emissions within the city boundaries and is a measure of the production side; SB-2 and SB-3 show indirect emissions from imports from outside the city boundaries and are a measure of the consumption side; and SB-4 shows direct and indirect emissions due to cities' consumption.

In the six major cities of Japan, despite the increase in production-based emissions under SB-1, the carbon mitigation responsibility of cities as indicated by SB-4 remained stable regardless of changes in the industrial structure. In Tokyo, the electricity supply from nuclear power plants changed, SB-2, which is the sum of direct emissions plus embodied electricity-based CO_2 emissions, increased, but SB-4, the carbon mitigation responsibility, changed only slightly. These results indicate that the carbon mitigation responsibility of Japan's major cities is stable regardless of social conditions, such as their energy supply and industrial structure.

Since this study uses input-output analysis, it is necessary to use the input-output tables prepared by six major cities and Tokyo. MRIO to be prepared by Tokyo is difficult to prepare not only for regional cities but also for GODLC. Therefore, we set a 20-year period to see the long-term changes in the carbon dioxide emission structure of Japan's major cities, and used SRIO from 1980 to 2000 for the six major cities and MRIO from 1990 to 2011 for Tokyo. Although there is a difference between the figures in MRIO and SRIO for Tokyo, the trend of carbon mitigation responsibility in Tokyo did not change. Therefore, it can be concluded that SRIO is sufficient to see the long-term changes in carbon mitigation responsibility in the six major cities with smaller economies than Tokyo.

The results show that unless Japan's major cities change their consumption habits and switch to electricity with a lower environmental burden, they will remain responsible for CO_2 emissions. In particular, electricity accounts for a high percentage of energy in major cities, and its consumption is increasing every year. Currently, Japan is switching to thermal power generation because nuclear power cannot be provided due to safety issues, which tends to increase the CO_2 emission intensity. To reduce the carbon mitigation responsibility of cities, we must not only save electricity but also work to promote and use renewable energy and other forms of electricity with a low CO_2 emission intensity to eliminate nuclear power.

The analysis of the four system boundaries is very useful in understanding the structure of urban emissions. In particular, SB-4 aims to accelerate the promotion of global warming countermeasures through urban policies by reducing not only direct emissions within cities but also indirect CO_2 emissions. To put measurement based on SB-4 into practical use, data will be obtained by fully considering grassroots actions in consumption activities such as energy-saving behavior and green purchasing and procurement. Although there are many issues to be addressed, such as improving this method, this study suggests the significance of such an approach.

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