Addressing Key Drivers of Regional CO_2 Emissions of the Manufacturing Industry in Japan

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ABSTRACT

This study investigated the factors behind the historical changes in CO_2 emissions of the Japanese manufacturing industry as a whole and by sector at the prefectural level. We decomposed the changes of CO_2 emissions in 47 prefectures from 1990 to 2013 into four factors (carbon intensity, energy intensity, structure, and activity effects) using the logarithmic mean Divisia index method. We found that energy intensity, structure, and activity effects were more influential in the changes of emissions than the carbon intensity effect, although the most influential factor varied by prefecture. Among the eight considered industrial sectors of Japan's manufacturing industry, the changes in the chemistry and metal sectors were particularly complex. Thus, improvements of the energy intensity and production in these two sectors should be prioritized. We also conducted detailed analysis of the decomposed factors in three selected prefectures based on cluster analysis.

Keywords: Decomposition analysis, CO_2 emissions, Manufacturing industry, Prefectural-level analysis, Japan

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1. INTRODUCTION

As a member country of the United Nations Framework Convention on Climate Change and as a signatory of the Kyoto Protocol, Japan has made efforts to reduce its greenhouse gas (GHG) emissions, particularly CO_2 emissions. Although Japan has not provided emissions reduction targets for the second commitment period of the Kyoto Protocol, it has continued its efforts toward emissions reduction. Japan ratified the Paris Agreement on November 8, 2016, and it has stated its aim of reducing its emissions by 2030 by 26.0% compared with 2013 levels.

Japan's CO_2 emissions trajectories by sector are shown in Figure 1. Total CO_2 emissions in Japan increased until the reduction caused by the global financial crisis of 2007–2008. Emissions in 2007 were 16.2% greater than in 1990. Emissions increased again after recovery from the economic crisis, but they decreased following the Great East Japan Earthquake in 2011. Nevertheless, emissions in 2015 were still 7.7% greater than 1990 levels. In 2015, emissions from Japan's manufacturing industry accounted for approximately one quarter (24.4%) of the total. In addition, if emis-

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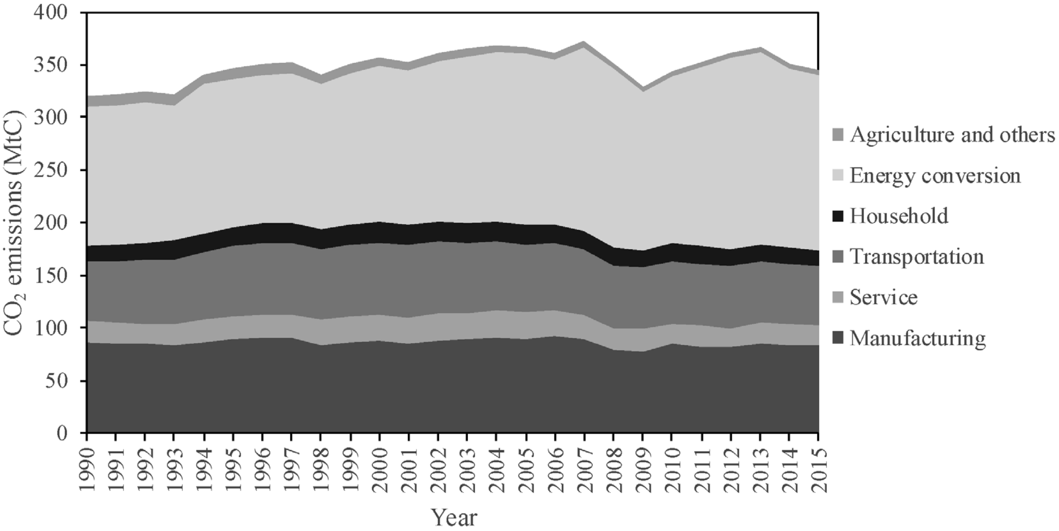
Figure 1: CO_2 emissions (direct emissions) by sector in Japan (1990–2015). The data for this figure are given in Appendix B (Table B1).



Source: Agency for Natural Resources and Energy (2017b).

sions derived from the energy conversion sector were allocated to energy (i.e., electricity and heat) consumers, emissions from the manufacturing industry would have accounted for approximately 40% of the total. Thus, this industry constitutes the major source of emissions in Japan, making the reduction of its emissions extremely important. Emissions from this industry increased from 1990 to 2007 by 7.1%, but they decreased after both the financial crisis and the Great East Japan Earthquake. Overall, emissions from the manufacturing industry have changed little during the previous 25 years; emissions in 2015 were 3.1% lower than the 1990 levels.

Various decomposition techniques have been used in numerous studies to investigate the factors behind the increases or decreases in the trends of time series of CO_2 emissions (Ang et al., 1998; Liaskas et al., 2000; Ang and Choi, 1997, 2002; Ang, 2005; Diakoulaki and Mandaraka, 2007; Shrestha et al., 2009; Bhattacharyya and Matsumura, 2010; Kumbaroğlu, 2011; O' Mahony et al., 2012; Xu and Ang, 2013, 2014; Jeong and Kim, 2013; Ren et al., 2014; Xu et al., 2014; Fernández González et al., 2014a, 2014b; Ouyang and Lin, 2015; Zhang and Da, 2015; Ang et al., 2015; Roinioti and Koroneos, 2017; Shigetomi et al., 2018).[1] Most such decomposition studies have been conducted at the national scale. For example, Xu and Ang (2013) undertook a comprehensive literature review on index decomposition analysis (IDA) and found that such studies have been conducted in developed to developing countries at national scales (and for various sectors including national total emissions). Xu et al. (2014) applied the logarithmic mean Divisia index (LMDI) method to carbon emissions from 1995 to 2011 in China. They decomposed the emissions into five factors (energy structure, energy intensity, industry structure, economic output, and population scale effects). They found that the major driver of carbon emissions was the economic output effect, followed by population scale and energy structure effects. There have also been previous studies

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[1] There are other decomposition studies related to this topic such as energy demand, energy efficiency, and energy intensity (Filippini and Hunt, 2006; Metcalf, 2008; Huntington, 2010; Mulder, 2015; Moshiri and Duah, 2016; Grossi and Mussini, 2017; Croner and Frankovic, 2018; Voigt et al., 2014). However, in the literature review, our focus was on decomposition analysis in relation to CO_2 emissions.

that have focused on Asian countries (Shrestha and Timilsina, 1996; Paul and Bhattacharya, 2004; Shrestha et al., 2009; Jeong and Kim, 2013; Ren, Yin and Chen, 2014; Ouyang and Lin, 2015; Zhang and Da, 2015), although few have considered Japan. One example of a decomposition study that did consider Japan was conducted by Henriques and Borowiecki (2017). They applied the extended Kaya decomposition technique to identify the drivers of long-term CO_2 emissions since 1800 for 12 developed countries, including Japan. Okamoto (2013) used the Shapley–Sun decomposition method to decompose the CO_2 emissions from domestic industries into five factors (changes in economic scale, industrial composition, energy intensity, import composition, and import scale), focusing on the impact of the growth of the service economy in Japan on changes to CO_2 emissions. Yabe (2004) performed decomposition analysis of Japanese industrial sectors from 1985 to 1995 using an input–output table. In their respective decomposition analyses, Greening (2004) and Lu et al. (2007) focused on the transportation sector in Japan (and other countries), while Malla (2009) focused on electricity generation.

The work by Luo et al. (2017) represents one of the few examples of an application of decomposition analysis at local scale (city level). They focused on the two cities of Shanghai and Tokyo and they compared their respective factors. Wang et al. (2018) is another example; they decomposed provincial CO_2 emissions in China into eight factors, highlighting the breakdown of the total emissions of each province. However, neither of these two studies undertook detailed analysis of the decomposed factors.

In Japan, the Act on Promotion of Global Warming Countermeasures constitutes the basic regulation to combat climate change. It stipulates the responsibilities of the national government, local government, and business operators are as follows. (1) The national government shall support the programs of local governments for the control of GHGs and endeavor to provide technical advice and other measures to promote activities by private entities. (2) Local governments shall endeavor to provide information and take other measures to promote activities by local businesses concerning the control of GHGs. (3) Business operators shall strive to develop measures for the control of GHGs regarding their business activities and cooperate with programs of the national government and local governments for controlling GHGs.[2] Based on the act, local governments (prefectures and cities) have established ordinances for global warming countermeasures. However, few of the ordinances propose regulations on the GHG emissions of the various industrial sectors, although some do include numerical targets (Chiba Prefecture 2015b). One example of a mandatory measure by local government on the business sector is the emissions trading scheme of Tokyo, which was launched in April 2010. It obliges large-scale business establishments, which consumed energy of 1500 kl of oil equivalent in the previous year, to reduce their CO_2 emissions and to participate in emissions trading (i.e., cap and trade). However, the main actions directed toward the mitigation of climate change by business entities in Japan have been based on the voluntary approach (Voluntary Action Plan on the Environment from 1997 and Commitment to a Low Carbon Society from 2013) by Keidanren (Japan Business Federation). These comprise voluntarily determined action plans for GHG emissions reductions by business associations (including 31 industry associations), and each association sets its own emissions reduction targets followed by reviews through the plan–do–check–act cycle. Therefore, the interactions between local governments and industrial sectors in relation to measures adopted to mitigate climate change are limited.

The Paris Agreement refers to the roles of non-state actors and therefore efforts at the local level are essential to the reduction of CO_2 emissions nationally. Prefectures in Japan are obliged to

[2] There are other responsibilities of the national and local governments in the act; however, only those related to interactions between the different entities are described here.

set their own targets and action plans for GHG emissions reductions. Because prefectures set ambitious targets, the combined target of all 47 prefectures is to reduce emissions by 2030 by 25.6%–28.0% compared with 2012 levels, which is greater than the national target (E-konzal and Kiko Network, 2016). To achieve this target and to set targets beyond 2030, it is crucial to identify those factors that drive prefecture-level CO_2 emissions. In particular, considering the emissions situation outlined above, the identification of such factors and their changes in relation to the manufacturing industry of each prefecture is essential. The studies by Yabe (2004) (Japan), Diakoulaki and Mandaraka (2007) (European Union), Jeong and Kim (2013) (Korea), Ren et al. (2014) (China), and Ouyang and Lin (2015) (China) are examples of the application of CO_2 emissions decomposition in the manufacturing industry; however, they only considered the national level.

The purpose of the present study was to adopt a decomposition approach (i.e., IDA) to investigate those factors behind the changes in CO_2 emissions between 1990 and 2013 in relation to the Japanese manufacturing industry. We implemented IDA at the prefectural rather than the national level. If we analyzed the factors at a national level, the effects would be averaged. By performing prefectural-level analysis, we could identify the factors behind the emissions increases/decreases in detail.

2. METHODS

2.1 Decomposition Approach

We conducted IDA to investigate those factors behind the changes in CO_2 emissions in the manufacturing industry of the 47 prefectures in Japan (Figure A1 in Appendix A). Four factors were considered in the decomposition: CO_2 emissions per energy use in sector *i* (carbon intensity effect), energy use per gross prefectural product (GPP) in sector *i* (energy intensity effect), share of GPP in sector *i* (structure effect), and total GPP in the manufacturing industry (activity effect).

There are several types of IDA method, e.g., the LMDI and Laspeyres index (Ang, 2004; Roinioti and Koroneos, 2017). We used the LMDI approach (Ang, 2005, 2015) because it has been used often in similar decomposition studies (Shrestha et al., 2009). Ang (2005, 2015) proposed two types of LMDI decomposition formula: multiplicative and additive decomposition and we chose to adopt the latter.[3]

The equations used for the decomposition analysis are shown in Eqs. [1]–[6]. Equation [1] represents the breakdown into the four factors of the total annual CO_2 emissions of the sectors of the manufacturing industry. Equation [2] shows the difference in emissions between two periods (*t*0 and *t*1). Equations [3]–[6] show the calculation of the impact of each factor on the total change in CO_2 emissions. These equations were applied to each prefecture. As in other studies of emissions decomposition, the present study used carbon intensity, energy intensity, structure, and activity effects as the decomposition factors. The combination of structure and activity effects can be interpreted as the production effect.

$$T\_Ems_t = \sum_i Ems_{i,t} = \sum_i \frac{Ems_{i,t}}{Ene_{i,t}} \frac{Ene_{i,t}}{Gpp_{i,t}} \frac{Gpp_{i,t}}{T\_Gpp_t} T\_Gpp_t = \sum_i cint_{i,t} eint_{i,t} pstr_{i,t} T\_Gpp_t \quad (1)$$

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[3] As a climate change measure, understanding the respective contributions of each factor and sector to the “amount” of CO_2 emissions is more important than the relative changes. Therefore, we applied additive decomposition in this study.

$$\Delta T\_Ems_t = T\_Ems_{t1} - T\_Ems_{t0} = \Delta T\_Ems_{cint,t1} + \Delta T\_Ems_{eint,t1} + \Delta T\_Ems_{pstr,t1} + \Delta T\_Ems_{T\_Gpp,t1} \tag{2}$$

$$\Delta T\_Ems_{cint,t1} = \sum_i \frac{Ems_{i,t1} - Ems_{i,t0}}{\ln Ems_{i,t1} - \ln Ems_{i,t0}} \ln\left(\frac{cint_{i,t1}}{cint_{i,t0}}\right) \tag{3}$$

$$\Delta T\_Ems_{eint,t1} = \sum_i \frac{Ems_{i,t1} - Ems_{i,t0}}{\ln Ems_{i,t1} - \ln Ems_{i,t0}} \ln\left(\frac{eint_{i,t1}}{eint_{i,t0}}\right) \tag{4}$$

$$\Delta T\_Ems_{pstr,t1} = \sum_i \frac{Ems_{i,t1} - Ems_{i,t0}}{\ln Ems_{i,t1} - \ln Ems_{i,t0}} \ln\left(\frac{pstr_{i,t1}}{pstr_{i,t0}}\right) \tag{5}$$

$$\Delta T\_Ems_{T\_Gpp,t1} = \sum_i \frac{Ems_{i,t1} - Ems_{i,t0}}{\ln Ems_{i,t1} - \ln Ems_{i,t0}} \ln\left(\frac{T\_Gpp_{t1}}{T\_Gpp_{t0}}\right) \tag{6}$$

where i: industry sector; t: year; T_Ems: total CO_2 emissions from manufacturing industry (ktC); Ems: sectoral CO_2 emissions (ktC); Ene: primary energy use (TJ); Gpp: GPP (million JPY); T_Gpp: total GPP of manufacturing industry (million JPY); $cint$: carbon intensity; $eint$: energy intensity; $pstr$: GPP share of sector i in the manufacturing industry; ΔT_Ems_x: change in total CO_2 emissions by factor x.

We decomposed the changes in CO_2 emissions of the manufacturing industry of the 47 prefectures from 1990 to 2013.

2.2 Data

The data used for the decomposition analysis were those of the variables in Eq. [1] (i.e., *Ems*, *Ene*, and *Gpp*) by prefecture and by sector. We obtained the data from the following sources. CO_2 emissions and energy consumption were from Energy Consumption Statistics by Prefecture (Agency for Natural Resources and Energy, 2017a). Although each prefecture publishes CO_2 emissions data based on calculation by the prefectural governments, we used data published by the Agency for Natural Resources and Energy (2017a) because of data consistency between CO_2 emissions and energy, plus consistency among prefectures.[4] GPP data by sector were obtained from Prefectural Accounts (Cabinet Office, 2017).

Among these data sources, the resolution of the sectoral structure varies. For example, data from the Agency for Natural Resources and Energy (2017a) are less detailed than from the Cabinet Office (2017). Therefore, if high-resolution classification were used, the data of the lower-resolution classification would have to be split to fit the high-resolution classification. However, this would demand some assumptions that might be unreasonable. Thus, we used the lower-resolution classification of data sources, i.e., the Energy Consumption Statistics (Agency for Natural Resources and Energy, 2017a). In this data source, the "manufacturing industry" is aggregated into eight industrial

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[4] Various data sources exist for CO_2 emissions and the values reported in each source differ to certain extents (Agency for Natural Resources and Energy, 2017a, 2017b; Greenhouse Gas Inventory Office of Japan, 2017). However, we used the Agency for Natural Resources and Energy (2017a), because it is the only data source that provides consistent time series CO_2 emissions by both prefecture and sector.

"sectors": 1) food and beverage sector (hereafter, *food* sector); 2) *textile* sector; 3) pulp, paper, and paper processing sector (*pulp and paper* sector); 4) *chemistry* sector; 5) *cement and ceramics* sector; 6) iron, steel, and non-ferrous metal sector (*metal* sector); 7) *machinery* sector; and 8) *other manufacturing* sector. Data from the Cabinet Office (2017) were aggregated into the above classifications.

We used direct emissions, meaning that CO_2 emissions from power generation were not allocated to electricity consumers. This is because CO_2 emissions from power generation cannot be controlled by the industrial sectors; thus, reducing such emissions is beyond the capabilities of the individual sectors.

The changes in CO_2 emissions, primary energy consumption, and gross domestic product (GDP) in the manufacturing industry at the national level, based on 1990 levels, are shown in Figure 2a. Table 1 also shows the corresponding statistical data in 1990 and 2013. At the national level, CO_2 emissions from the manufacturing industry increased from 1990 to 1997 and then remained stable until 2007. However, emissions decreased from 2007 to 2009 because of the global financial crisis of 2007–2008. Although CO_2 emissions increased slightly in 2010, they decreased again because of the Great East Japan Earthquake in 2011. CO_2 emissions in 2013 were 0.06% lower than the 1990 level. The trend of change of primary energy consumption was similar to that of CO_2 emissions until the mid-1990s. However, from the end of the 1990s, primary energy consumption increased at a greater rate than CO_2 emissions (compared with the 1990 level). The trend of change of GDP was different from those of CO_2 emissions and energy consumption. Total GDP of the manufacturing industry declined from 1990 until 2001 but it then recovered up to 2007. However, it declined again because of the financial crisis. It recovered after 2009 but the GDP in 2013 was 7.8% lower than the 1990 figure. Interestingly, GDP in Japan increased over the same period, which indicates that the Japanese economy moved toward a service economy. In the manufacturing industry, the sectoral structure has also changed (Figure 2b). During the previous 25 years, the GDP shares of the *chemistry* and *food* sectors increased by 4.5 and 4.2 percentage points, respectively, while that of the *metal* sector decreased by 2.7 percentage points.

The changes in CO_2 emissions, primary energy consumption, and GPP in the manufacturing industry by prefecture, relative to 1990 levels, are shown in Figure 3. CO_2 emissions decreased in 36 prefectures, and the largest emissions reduction was in Tokyo. The changes in emissions were found correlated strongly with changes in primary energy consumption (correlation coefficient: 0.87); however, in a few prefectures, emissions did decline while energy use increased. Changes in CO_2 emissions and GPP were found uncorrelated (correlation coefficient: 0.07).

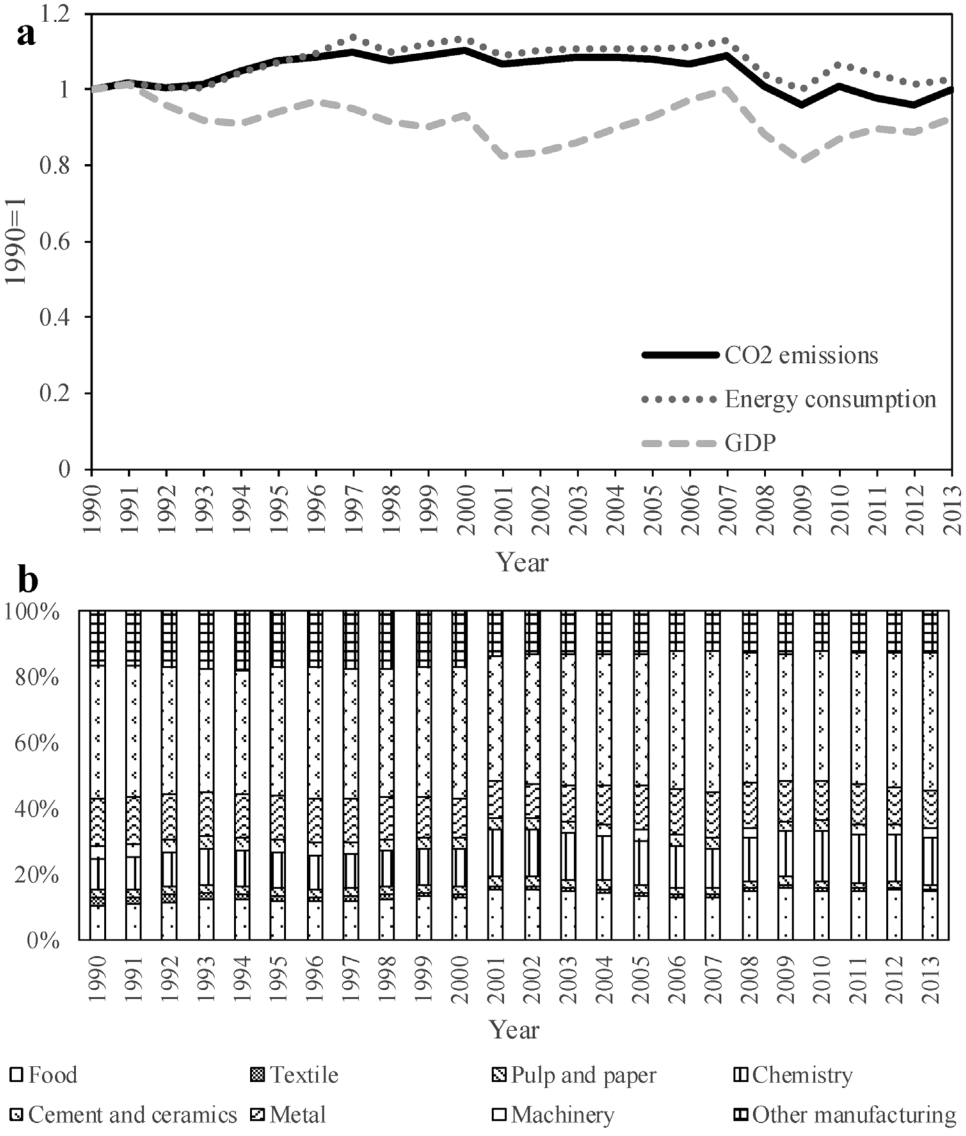
3. RESULTS AND DISCUSSION

3.1 Emissions Changes and Factors in the 47 Prefectures

3.1.1 Industrial and Sectoral Emissions at Prefectural Level

From 1990 to 2013, CO_2 emissions in the manufacturing industry reduced in 36 of the 47 prefectures (Figures 4 and 5). The largest reductions were in Osaka in terms of amount (2007 ktC; −31.3% relative to the 1990 level) and in Tokyo in terms of percentage (1048 ktC; −58.9% relative to 1990). In contrast, prefectures with the largest emissions increases were Chiba in terms of amount (17892 ktC; 14.0% increase over the 1990 level) and Miyagi in terms of percentage (677 ktC; 69.2% increase over 1990). Overall, in the prefectures with reduced emissions compared with the 1990 level, such as Fukuoka, Okinawa, Osaka, and Tokyo, emissions have declined continuously (Figure

Figure 2: Changes in CO_2 emissions, primary energy consumption, and GDP of the manufacturing industry (a; 1990 = 1) and changes in the structure of GDP (b).



Source: Agency for Natural Resources and Energy (2017a) and Cabinet Office (2017).

5). In prefectures with increased emissions compared with 1990, such as Miyagi, Chiba, Ehime, and Ibaraki, emissions have increased gradually, except in Miyagi, which was impacted severely by the Great East Japan Earthquake in 2011. In Miyagi, emissions increased rapidly during the year following the earthquake because of the swift recovery of economic activities (Cabinet Office, 2017).

The main cause of the increase in emissions in those prefectures that experienced increases was the *chemistry* sector (Figure 4). For example, in Ibaraki, Chiba, Kanagawa, and Yamaguchi, emissions from that sector increased by more than 2000 ktC during the study period. Prefectural CO_2 emissions can be increased by (a) the movement of plant from other prefectures and (b) the establishment of new plant or increases in the scale of preexisting plant within the prefecture. How-

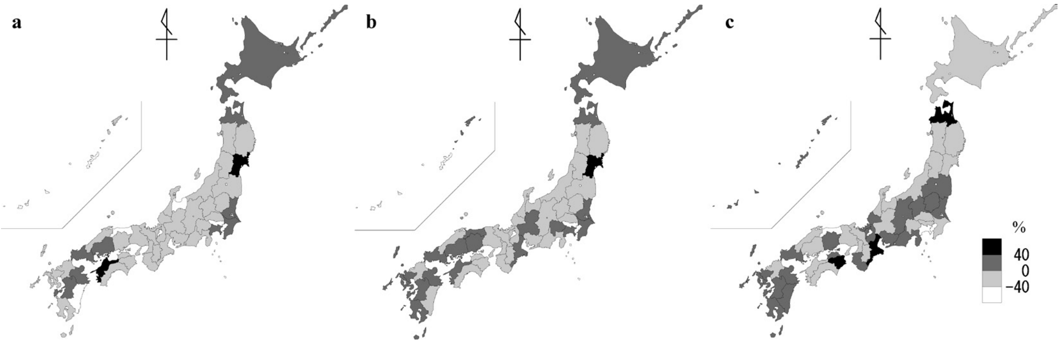
Table 1: Statistical data for the manufacturing industry (national total) in the base year (1990) and in 2013

	1990			2013		
	CO_2 (ktC)	Energy consumption (PJ)	GDP (billion JPY)	CO_2 (ktC)	Energy consumption (PJ)	GDP (billion JPY)
Manufacturing (total)	86,781.2	6349.9	111,552.7	85,512.6	5950.1	102,814.2
Food	1640.6	190.8	11,811.8	1665.0	214.0	15,197.5
Textile	747.1	176.1	2708.5	751.8	118.8	771.4
Pulp & paper	649.3	428.6	2742.2	566.3	339.9	1547.9
Chemistry	26,657.5	2065.3	10,487.3	34,071.9	2419.4	14,330.1
Cement & ceramics	11,265.7	638.4	4390.5	8155.7	485.6	3096.5
Metal	42,636.8	2125.6	15,946.8	38,747.2	1979.2	11,974.6
Machinery	3209.7	626.6	45,034.0	1549.0	345.9	43,079.5
Other	519.5	196.6	18,431.6	841.8	142.5	12,851.3

Source: Agency for Natural Resources and Energy (2017b) and Cabinet Office (2017).

Note: Manufacturing (total) reflects duplication correction for CO_2 emissions and energy consumption.

Figure 3: Changes in CO_2 emissions (a), primary energy consumption (b), and GPP (c) in the manufacturing industry by prefecture in 2013, relative to 1990 levels.

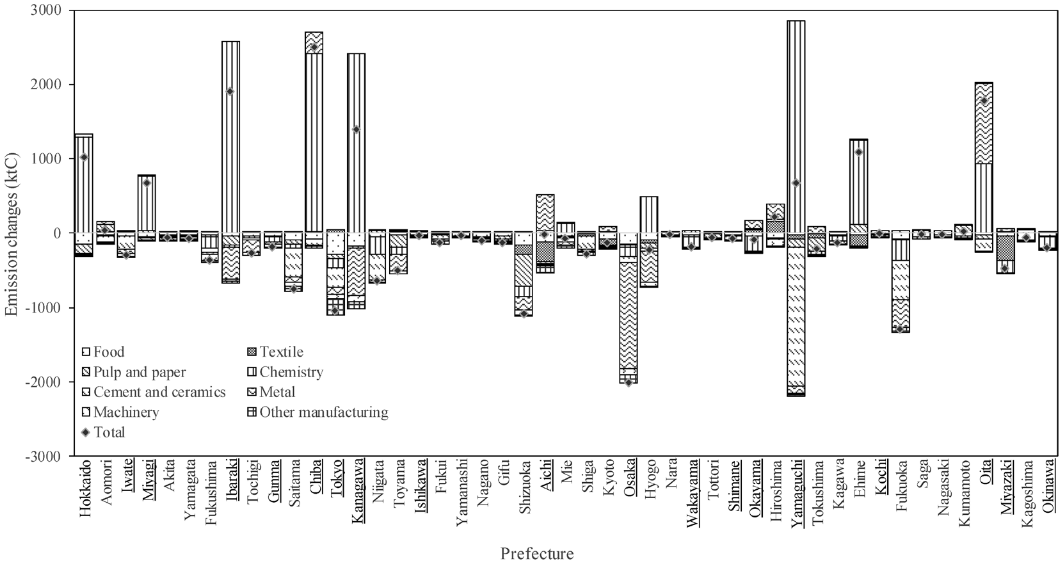


Source: Agency for Natural Resources and Energy (2017a).

ever, considering the emissions increases in this sector nationwide, the latter is considered the main reason for the prefectural increases.

The patterns of emissions reduction by sector were found to vary by prefecture (Figure 4). In the *food*, *metal*, *machinery*, and *other manufacturing* sectors, emissions were reduced in over 70% of prefectures. Conversely, emissions decreased in only 31.9% of prefectures in the *textile* sector. Other notable features were as follows. The *chemistry* sector was the most influential in many prefectures regarding emissions changes. Emissions from this sector increased substantially in some prefectures, e.g., Chiba, Yamaguchi, and Ibaraki. The emissions reduction in this sector was the largest within the manufacturing industry in prefectures such as Gunma, Wakayama, Okayama, and Okinawa. In other prefectures, the *metal* sector was influential (the second most influential within the manufacturing industry). In prefectures such as Oita, Aichi, and Chiba, emissions from this sector increased substantially, while those in Osaka, Kanagawa, and Ibaraki decreased considerably. The *cement and ceramics* sector was influential (third most influential) in prefectures such as Ishikawa, Kochi, and Miyazaki in terms of increases, and in Iwate and Shimane in terms of decreases. Osaka was the only prefecture that produced reduced emissions in all sectors.

Figure 4: CO_2 emissions changes between 1990 and 2013.



Notes: Bars represent sectors and the dots represent the total emissions changes of the manufacturing industry. Prefectures identified by underlines are discussed in the text in relation to this figure. The sum of the total emissions changes of the manufacturing industry in the 47 prefectures is slightly negative, which is consistent with the emissions changes shown in Figure 2.

Figure 5: Transition of CO_2 emissions in selected prefectures (i.e., top two prefectures with greatest increases/decreases of emissions in terms of both amount or percentage between 1990 and 2013; 1990 = 1).

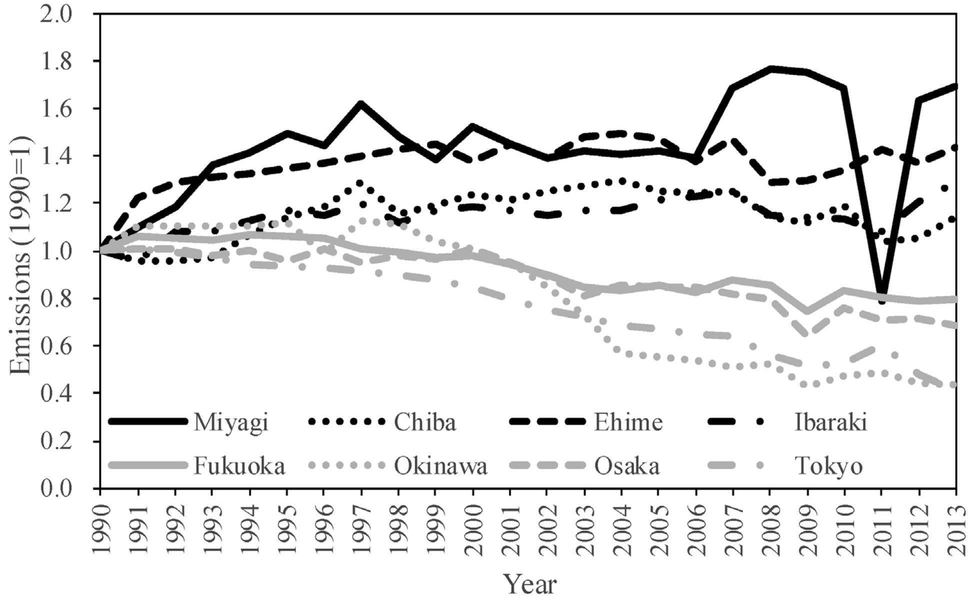
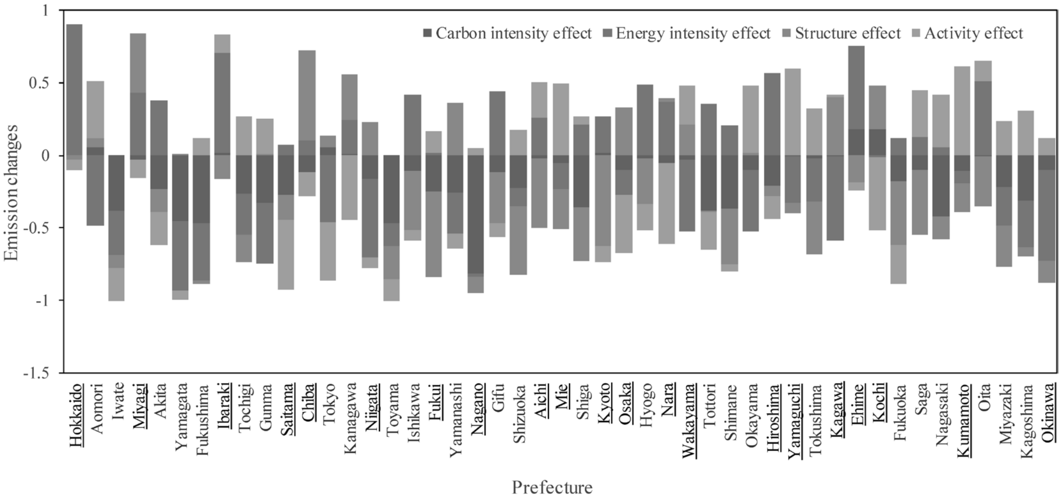


Figure 6: Factors of CO_2 emissions changes in the manufacturing industry between 1990 and 2013.



Notes: Values of each factor are normalized such that total length of each bar is one. Prefectures identified by underlines are discussed in the text in relation to this figure.

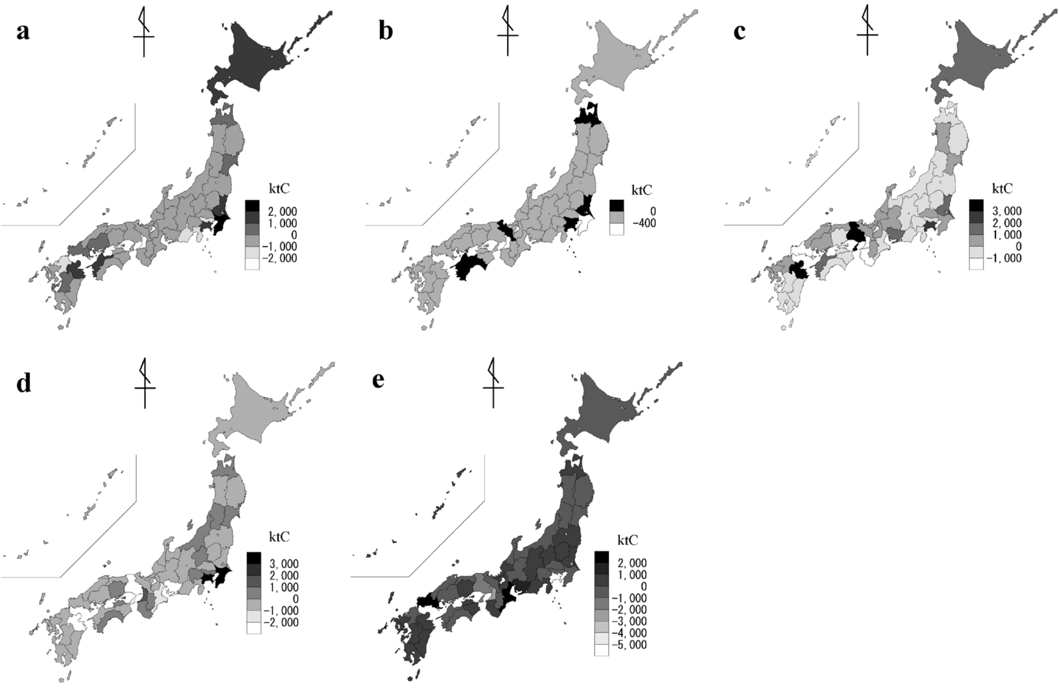
3.1.2 Carbon Intensity Effect in Manufacturing Industry

From the decomposed factors of emissions changes (Figures 6 and 7), it was found that the patterns of the factors varied by prefecture. Overall, the carbon intensity effect was negative, meaning that the energy mix of the entire manufacturing industry changed toward low carbon during the study period in many prefectures, although the effect was positive in a few prefectures. In those prefectures with positive changes, the increases were not large and therefore their contributions to CO_2 emissions increases were not substantial (390 ktC in Ehime was the maximum). However, in Ehime and Kochi, the contributions of the positive carbon intensity effect were large compared with other prefectures (Figure 6). In those prefectures where the carbon intensity effect contributed to emissions reductions, the scale varied by prefecture. The contribution of the carbon intensity effect to emissions reduction was large in terms of amount in both Chiba (665 ktC) and Osaka (585 ktC) (Figure 7), although it was not large relative to the other factors in these prefectures (Figure 6). In relative terms, the contribution of the carbon intensity effect to emissions reduction was large in Nagano, explaining 81.3% (negative) of the change. Carbon intensity can be altered by various phenomena, e.g., it can increase (decrease) if more (less) carbon-intensive energy is used in a particular sector, or if the share of production from carbon-intensive sectors or plant increases (decreases) relative to less carbon-intensive sectors or plant.

3.1.3 Energy Intensity Effect in Manufacturing Industry

The trends of the changes (increase/decrease) in the other factors (i.e., energy intensity, structure, and activity effects) differed by prefecture, although the number of prefectures with negative changes was larger. Of the four factors, the contribution of the energy intensity effect to the increase in CO_2 emissions was largest, and energy intensity increased in 23 of the 47 prefectures. Large increases were observed in Hyogo, Oita, and Kanagawa, and energy intensity was the main factor responsible for the changes of CO_2 emissions in Hyogo and Oita. In addition, in relative

Figure 7: Changes in CO_2 emissions (a) and the four factors (b: carbon intensity effect, c: energy intensity effect, d: structure effect, and e: activity effect) by prefecture (total of manufacturing industry; unit: ktC).



terms, the energy intensity effect contributed strongly to the increase of emissions in Hokkaido, Ibaraki, and Hiroshima (Figure 6). In contrast, the energy intensity effect was the most important factor in the emissions reductions in Wakayama, Yamaguchi, and Osaka in terms of amount, particularly in Wakayama. It was also a relatively important factor among the four. In relative terms, the contribution of the energy intensity effect to emissions reduction was considerable in Okinawa, Kagawa, and Niigata. Similar to carbon intensity, energy intensity will increase (decrease) if the share of energy-intensive sectors in production or of energy-intensive products in a sector increases (decreases) relative to less-energy-intensive sectors.[5]

3.1.4 Structure and Activity Effects in Manufacturing Industry

The structure and activity effects are related to production in the manufacturing industry. The prefectures with the greatest increases in emissions because of the structure effect were Chiba, Tokyo, and Osaka (e.g., the increase was 3478 ktC in Chiba). This means that in these prefectures, the share of the sectors with relatively high carbon intensity increased. In contrast, the structure effect was negative in Hyogo, Aichi, Oita, and Mie, meaning that the share of the sectors with relatively high carbon intensity decreased in these prefectures. In relative terms, among the four factors,

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[5] Among the eight sectors, the *textile*, *pulp and paper*, *chemistry*, *cement and ceramics*, and *metal* sectors showed higher energy intensity than the average for the manufacturing industry (in the national total of 2013). The *pulp and paper* sector was the most energy intensive and the *chemistry* sector was second.

the structure effect contributed strongly to the increases of emissions in Chiba, Miyagi, and Kagawa and to the decreases of emissions in Kyoto, Fukui, and Aichi (Figure 6).

The impact of the activity effect on the increase of emissions was powerful in Mie, Yamaguchi, and Aichi (2250, 2048, and 1057 ktC, respectively), meaning that the GPP of the manufacturing industry increased considerably in these prefectures. In contrast, the impact was strongly negative in Kanagawa, Osaka, and Hyogo. In these prefectures, decreases of the GPP in the manufacturing industry contributed to the reduction of emissions. In relative terms, among the four factors, the activity effect contributed substantially to the increase of emissions in Kumamoto, Yamaguchi, and Mie and to the decrease of emissions in Nara, Kochi, and Saitama.

The aggregated production effect (i.e., the total of the structure and activity effects) was largest in Chiba (2581 ktC) toward increasing emissions, while it was largest in Hyogo (−3329 ktC) toward decreasing emissions. In Hyogo, both the structure and activity effects were negative, although the former was more influential than the latter. In Chiba, however, the structure effect was positive and most influential in terms of the change of emissions, while the activity effect was negative and less influential.

3.1.5 Comparison of the Four Factors in the Manufacturing Industry

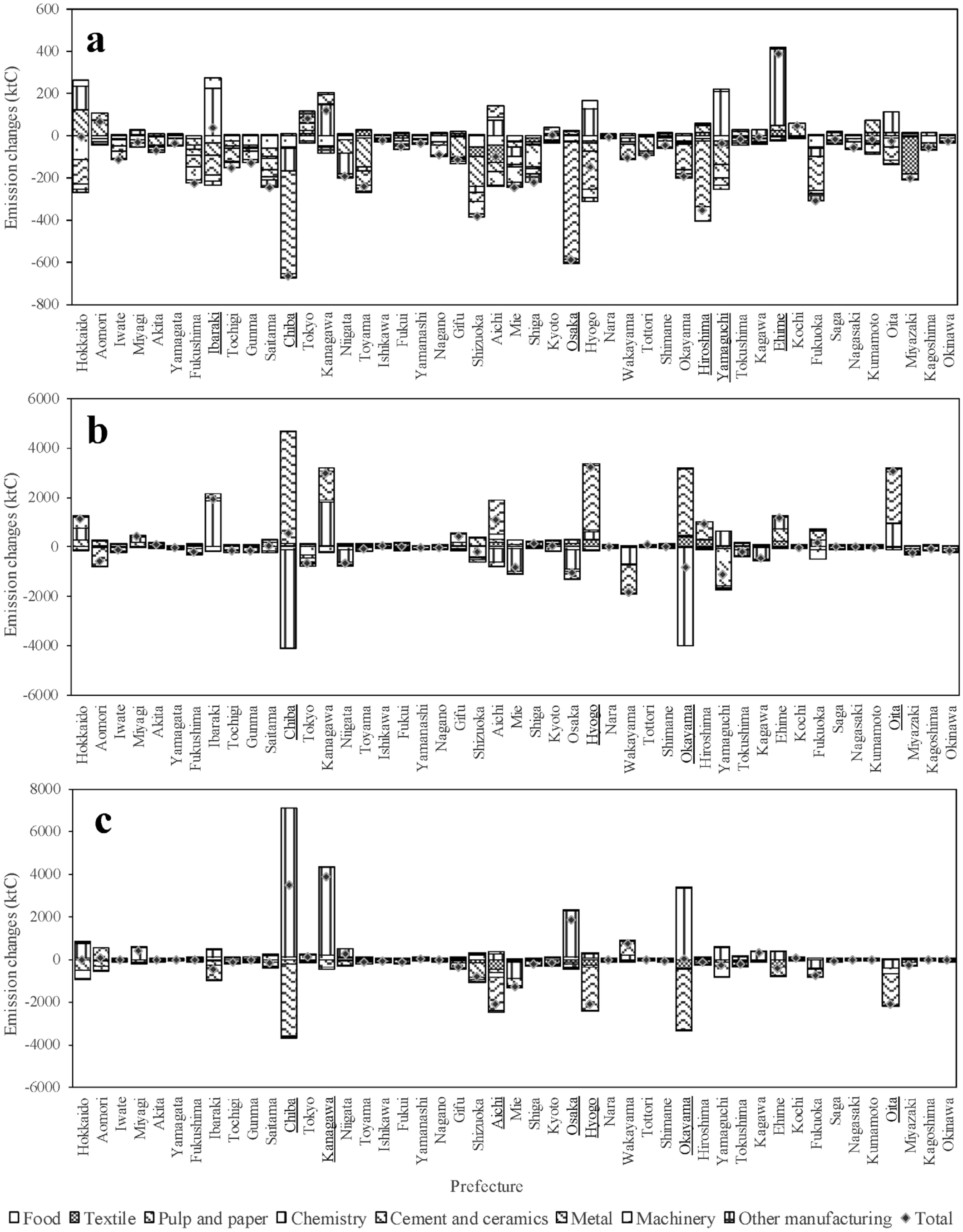
Comparison of the four factors revealed that the contribution of the carbon intensity effect to the changes of CO_2 emissions was much smaller than that of the other three factors (Figure 7). The largest changes between 1990 and 2013 were −665 (negative) and 390 (positive) for carbon intensity, and −1820 to −5591 (negative) and 2250 to 3894 (positive) for the other factors. Among the three other factors, the numbers of prefectures whose energy intensity and activity effects were negative or positive were nearly equal (i.e., 24 negative and 23 positive). However, on average, the positive effect was stronger in terms of energy intensity and the negative effect was stronger in terms of the activity effect. Although the structure effect was negative in 32 prefectures, it was found as a factor that increased emissions on average.

3.1.6 Factors by Industrial Sector

To analyze each factor further, they were disaggregated into eight industrial sectors (Figure 8). The activity effect was not disaggregated because it represents the effect of the entire manufacturing industry (see Eq. [1]). Overall, of the eight sectors, the *chemistry* and *metal* sectors were the two most influential.

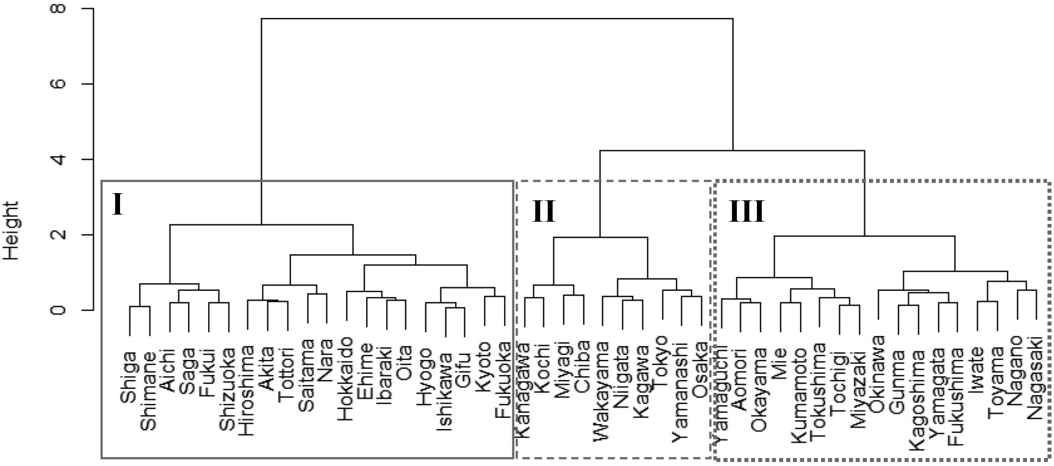
Carbon intensity changes depending on the energy mix within a sector. Thus, in each sector and prefecture, negative values of the carbon intensity effect indicate the sector used less carbon-intensive energy because of either conversion to low-carbon energy or an increase in the share of less-carbon-intensive products within the sector. On average, the *chemistry* sector was the one that showed an increase in carbon intensity, although its magnitude was small. Although carbon intensity in the *chemistry* sector improved in some prefectures, there were increases in a greater number of prefectures and the magnitudes of these changes were large, particularly in Ehime, Ibaraki, and Yamaguchi. Among the other sectors, the contribution of the *metal* sector to emissions reduction was the greatest. Although some prefectures had increases of carbon intensity in relation to the *metal* sector, the increases were small, and many more prefectures had improved carbon intensity with larger magnitudes, e.g., Chiba, Osaka, and Hiroshima. Such differences in carbon intensity change

Figure 8: Disaggregation of carbon intensity effect (a), energy intensity effect (b), and structure effect (c) by sector.



Notes: Bars represent sectors and the dots represent the total changes of the manufacturing industry. Prefectures identified by underlines are discussed in the text in relation to this figure. Activity effect is not shown because it is the aggregated term of the entire manufacturing industry.

Figure 9: Cluster analysis using four factors. The Ward method was used for the clustering.



in each sector by prefecture might have occurred because of changes in structure and technology (e.g., a switch in energy sources) within the sector.

The energy intensity effect indicates the extent to which more/less energy was used per GPP in each sector and prefecture. In contrast to carbon intensity, the *metal* sector was the one that increased emissions via energy intensity, and the increases were particularly large in Hyogo, Oita, and Chiba. On average, the energy intensity effect of the *chemistry* sector was negative, and it was especially large in Chiba and Okayama. The reasons behind these results might be changes in the structure of energy-intensive or less-energy-intensive products in each sector.

Observing the structure effect (or changes in GPP share), the *chemistry* and *metal* sectors were the two most influential in relation to emissions changes; the *chemistry* sector contributed to an increase in emissions, whereas the *metal* sector contributed to a decrease. In particular, the *chemistry* sector in Chiba, Kanagawa, Okayama, and Osaka and the *metal* sector in Chiba, Okayama, Aichi, Hyogo, and Oita had powerful influences on the changes.

By disaggregating the three factors to the sectoral level, the detailed contributions of each factor and sector to the changes in CO_2 emissions were determined. This was important because these effects would have been offset had the decomposition of the CO_2 emissions simply considered the manufacturing industry as an entity (Figure 4). Overall, the impacts of the *chemistry* and *metal* sectors were strong for the three effects. However, in the aggregated CO_2 emissions, the impact of the *metal* sector was weaker. Contributions of the other sectors to the changes in emissions were much smaller for the three factors.

3.2 Case Studies

To elucidate further details of the emissions reduction factors, we conducted case studies for selected prefectures. We selected one prefecture from each of the groups composed of prefectures that had similar factors in terms of emissions changes.

3.2.1 Similarities in Factors of Emissions Changes

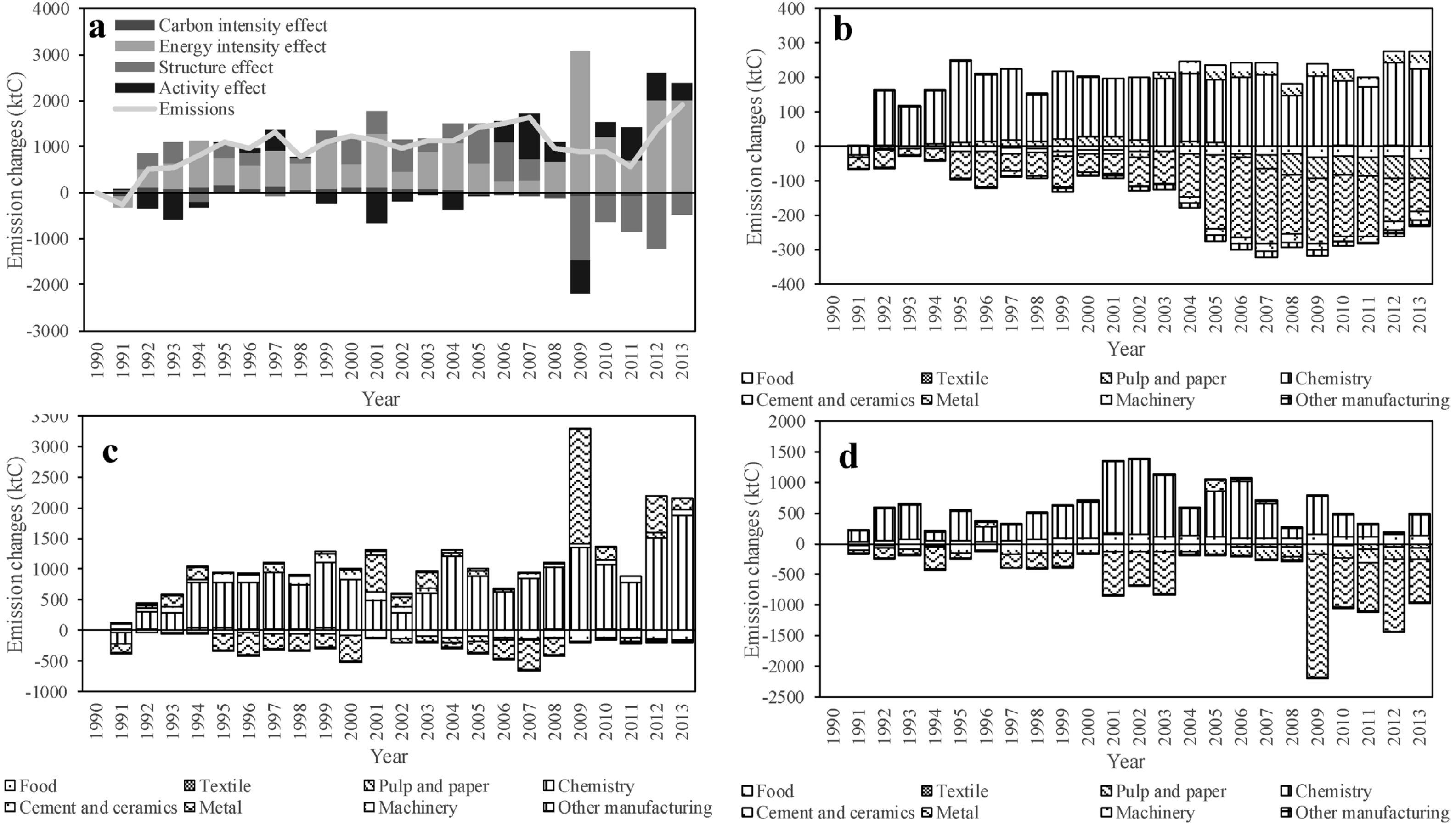
We used a cluster approach to identify similarities in the emissions changes of the prefectures (Figure 9). The variables used for the cluster analysis were the four factors (i.e., carbon intensity, energy intensity, structure, and activity effects) and the samples were the prefectures. The data for each variable were the changes between 1990 and 2013, the values of which were normalized such that the sum of the absolute values of the four factors was 1 for each prefecture. Therefore, the data used for this analysis were same as used in Figure 6. With this analysis, we identified three clusters. Cluster I (solid line) indicates that the difference in the contributions of the energy intensity and structure effects to emissions changes was larger than in the prefectures in the other clusters. Cluster II (dashed line) shows that the structure effect was positive and larger than that of the prefectures in the other clusters. Cluster III (dotted line) shows that the energy intensity effect was negative and small. In addition, the difference in the contributions of the energy intensity and structure effects to emissions changes was smaller for Clusters II and III than for Cluster I. Here, we discuss the results for three prefectures: Ibaraki (Cluster I), Chiba (Cluster II), and Kumamoto (Cluster III), which showed the largest emissions changes in each cluster based on Figure 9.

3.2.2 Ibaraki

Ibaraki is in the Kanto area (Figure A1). Figure 10 shows the time series results of the decomposition of CO_2 emissions by the four factors and for each factor by sector in Ibaraki. The activity effect was not disaggregated (and not shown as a separate panel in Figure 10) because it is the aggregated term of the entire manufacturing industry. In Ibaraki, CO_2 emissions increased gradually from 1990, although they declined after the global financial crisis of 2007–2008 and the 2011 earthquake. After the earthquake, emissions increased again (Figure 10a). The most influential factor in the emissions increase was the energy intensity effect, which was positive after 1991. Values of the energy intensity effect fluctuated around 1000 ktC until 2008. However, they increased substantially in 2009 and subsequently remained large. In contrast, the structure effect was positive before 2008 but it then became negative. This implies that after the financial crisis, the share of carbon-intensive sectors decreased in Ibaraki. The impact of the carbon intensity effect was negligible. Ibaraki is easily accessible to the Tokyo metropolitan area and it has preferential support systems regarding newly established business facilities (e.g., exemption of prefectural tax and finance for firms that establish factories in industrial complexes) (Nihon Sanki Shimbun, 2015). Consequently, the prefecture attracts those manufacturing firms that are among the best in the country. Conversely, because of the progress in the countermeasures by the national government, such as the requirement to report GHG emissions against large-scale business entities under the Act on Promotion of Global Warming Countermeasures (Ibaraki Prefecture, 2017a, 2017b), the local government does not impose individual mandatory measures for emissions reduction against industry. Because of these factors, emissions have increased in Ibaraki.

Examination of the three factors by sector revealed the evident influence of the *chemistry* and *metal* sectors (Figure 10b–d). The *chemistry* sector was the most influential and positive of the three, meaning that it was the main sector responsible for emissions increases in Ibaraki, especially in terms of the energy intensity effect in recent years. In contrast, the *metal* sector had a largely positive energy intensity effect in 2009, but it contributed mainly to emissions reduction, particularly in relation to the structure effect in recent years. Overall, this sector contributed to the reduction of emissions. Compared with the *metal* and *chemistry* sectors, the contributions of the other sectors were minor.

Figure 10: Time series of decomposition of CO_2 emissions of the manufacturing industry by the four factors in Ibaraki (comparison with 1990 level, a); disaggregation of three factors by sector (b: carbon intensity effect, c: energy intensity effect, and d: structure effect).



Notes: Activity effect is not shown because it is the aggregated term of the entire manufacturing industry.

3.2.3 Chiba

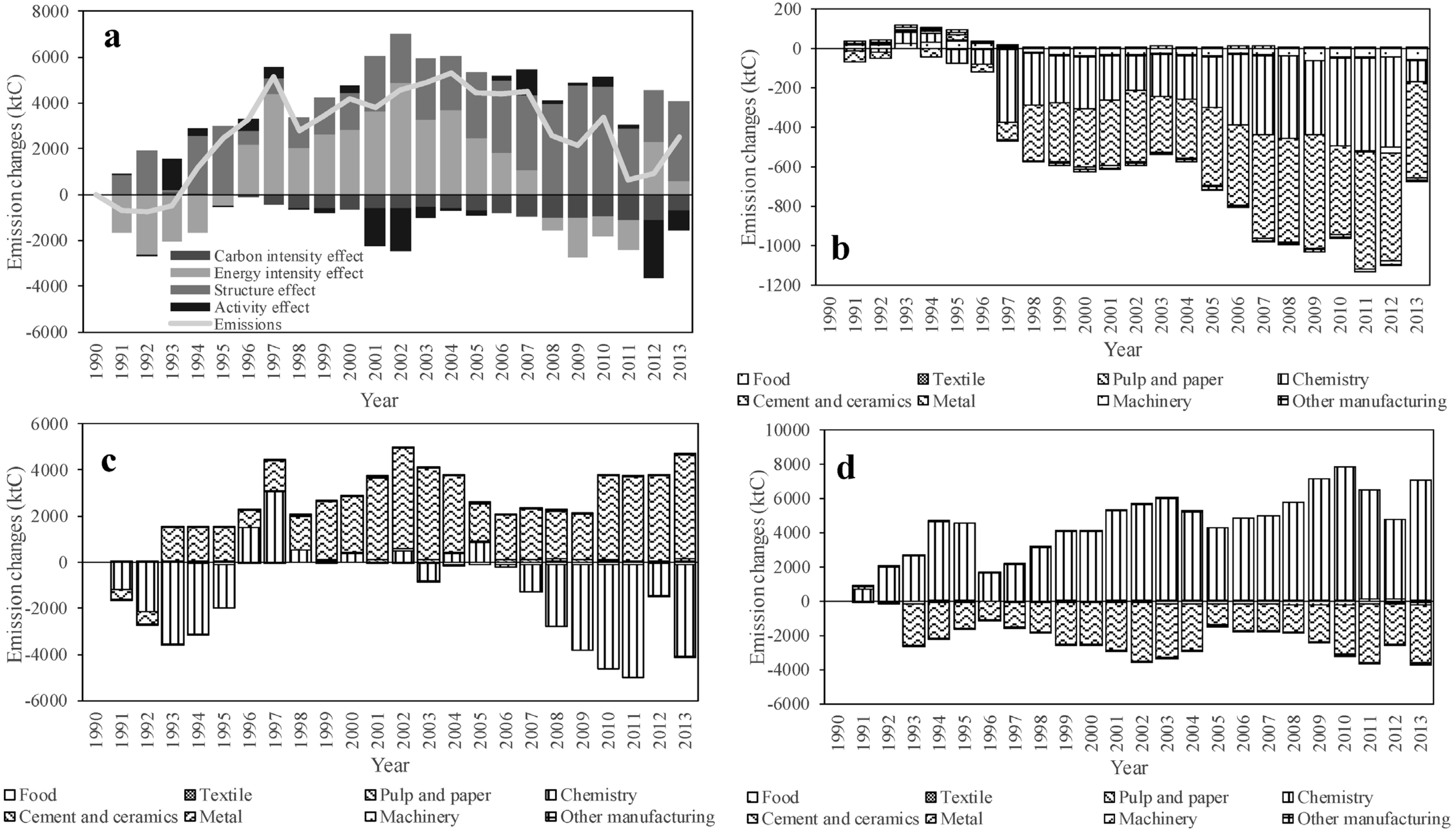
Chiba, which is also in the Kanto area (Figure A1), was established as the prefecture with the largest emissions increases of the Japanese manufacturing industry in the previous 25 years (Figures 4 and 7a). Figure 11 shows the time series results of CO_2 emissions decomposition by the four factors and for each factor by sector in Chiba. In this prefecture, similar to Ibaraki, CO_2 emissions increased gradually from 1990. However, emissions declined after 2004, with further decreases following the financial crisis of 2007–2008 and the 2011 earthquake, although they did increase again after the earthquake (Figure 11a). Current emissions remain higher than the 1990 level. The most influential factor varied depending on the year. In the late 1990s to early 2000s, the energy intensity effect was the most influential, but the structure effect has been the most prominent since the mid-2000s. The carbon intensity effect was stronger than found in Ibaraki, but it was still smaller in relation to the other factors.

Similar to Ibaraki, scrutiny of the three factors revealed the noticeable influence of the *chemistry* and *metal* sectors (Figure 10b–d). An important feature in relation to Chiba, in comparison with Ibaraki, was that carbon intensity was negative in most of the sectors and years, particularly after 1996. For the energy intensity effect, the *metal* sector contributed to increasing emissions during the previous 25 years, while the *chemistry* sector contributed to reducing emissions in the early 1990s and after 2006. The Plan for Global Warming Countermeasures of Chiba set targets regarding energy consumption or carbon emissions for the manufacturing industry in 2006 (Chiba Prefecture, 2015b). This target for the *chemistry* sector (energy intensity improvement of 10.0% from 1990 levels) might have contributed to the energy intensity improvement, although the CO_2 emissions of this sector increased because of the structure effect. Similarly, the above plan also set a target for sectors other than *chemistry* and *metal* (10.0% improvement of CO_2 emissions per production from the 2002 level), and this target (approximately the sum of the carbon and energy intensity effects for all sectors other than *chemistry* and *metal* in this study) has been achieved. Although an energy intensity target (10.0% improvement of energy intensity) was also set for the steel sector (included in the *metal* sector in our analysis), the energy intensity of the *metal* sector has worsened because of the decline in steel production in Chiba (Chiba Prefecture, 2015a). Finally, the structure effect indicates that the *chemistry* sector contributed strongly to increasing CO_2 emissions and that the total for the three factors was positive. The main reason for this increase might be that Chiba's industrial development policy is to strengthen the competitiveness of the Keiyo Industrial Complex, in which the petrochemical industry is the main industry (Chiba Prefecture, 2014, 2016). Thus, because of this policy, the share of the *chemistry* sector has increased. In the *metal* sector, the structure effect was negative, which is consistent with Chiba Prefecture (2015a), although the change from 1993 to the present was minor. The structure effect of the *chemistry* sector and the energy intensity effect of the *metal* sector were the major reasons for the emissions increases in Chiba.

3.2.4 Kumamoto

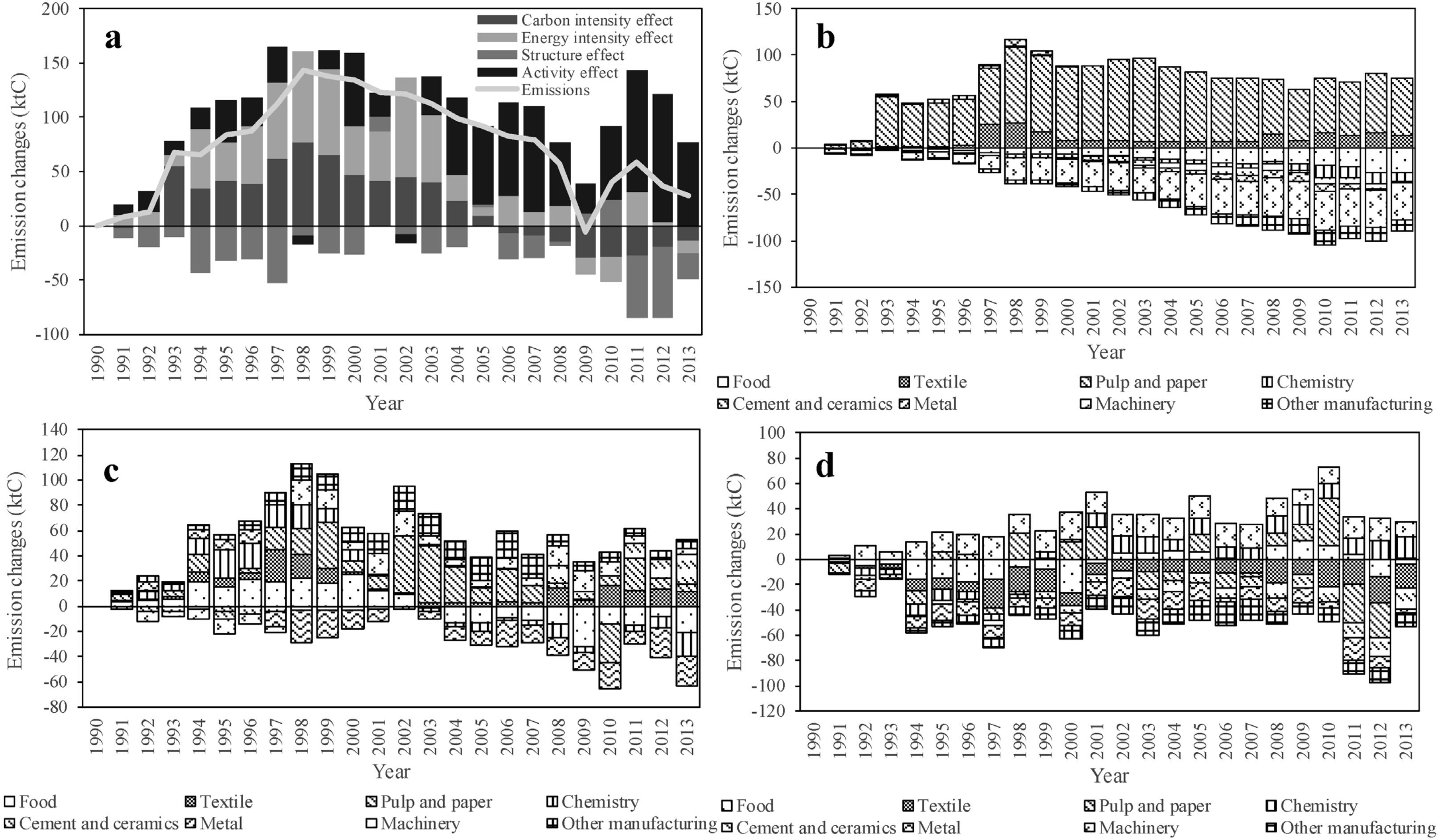
Kumamoto is in the Kyushu area (Figure A1). Figure 12 shows the time series results of CO_2 emissions decomposition for the four factors and for each factor by sector in Kumamoto. Compared with the previous two prefectures discussed, the emissions in Kumamoto were weak (Figure 12a), mainly because of the economic scale. In Kumamoto, although CO_2 emissions increased until 1998, they decreased subsequently. The impact of the 2007–2008 financial crisis was greater than in the other two prefectures. Because of the crisis, emissions in 2009 became lower than the 1990

Figure 11: Time series of decomposition of CO_2 emissions of the manufacturing industry by the four factors in Chiba (comparison with 1990 level, a); disaggregation of three factors by sector (b: carbon intensity effect, c: energy intensity effect, and d: structure effect).



Notes: Activity effect is not shown because it is the aggregated term of the entire manufacturing industry.

Figure 12: Time series of decomposition of CO_2 emissions of the manufacturing industry by the four factors in Kumamoto (comparison with 1990 level, a); disaggregation of three factors by sector (b: carbon intensity effect, c: energy intensity effect, and d: structure effect).



Notes: Activity effect is not shown because it is the aggregated term of the entire manufacturing industry.

level. The other difference from the above two prefectures was that because of the distance from the affected area, CO_2 emissions in Kumamoto were unaffected by the Great East Japan Earthquake. Furthermore, the contribution of the carbon intensity effect was larger than in the above two prefectures. In the 1990s to early 2000s, the factors governing emissions increases in Kumamoto were mainly the carbon and energy intensity effects. However, after the mid-2000s, the activity effect became the dominant factor in the modification of emissions.

Compared with the above two prefectures, the impacts of the *chemistry* and *metal* sectors were slight and spread across all sectors (Figure 12b–d). This is mainly because Ibaraki and Chiba are in a coastal industrial zone suitable for the location of heavy industry. The carbon intensity effect was positive and relatively large in the *pulp and paper* sector in Kumamoto; i.e., it increased in 1993 but decreased slightly in the 2000s. In this sector, the conversion from heavy oil to coal as a fuel has been promoted since the 1980s (Japan Paper Association, 2015). In addition, since 2003, the conversion from heavy oil to biomass energy has been promoted. These trends in fuel conversion might have affected the carbon intensity in the *pulp and paper* sector. This positive carbon intensity effect is larger than the negative effects in the other sectors; however, the negative effects have increased gradually and they have offset the positive effect since the mid-2000s. For the other two factors, the impacts for each sector were diverse. For example, the *machinery* sector tended to contribute positively (i.e., increasing emissions) to the two factors, while the *metal* sector tended to contribute negatively (i.e., decreasing emissions). Other sectors such as *cement and ceramics* and *chemistry* either positively or negatively contributed to each factor. These results might be because Kumamoto does not depend on a specific manufacturing industry.

4. CONCLUDING REMARKS

In this study, we decomposed changes in CO_2 emissions from the Japanese manufacturing industry (and its eight sectors) at the prefectural level from 1990 to 2013 into four factors. Although CO_2 emissions of the entire Japanese manufacturing industry have remained nearly stable since 1990, emissions have decreased in 36 prefectures over that period. By decomposing the changes, we elucidated those sectors/factors that had caused substantial influence. The following findings emerged from our decomposition analysis.

1) The types and magnitudes of the influential factors regarding emissions changes varied by prefecture.
2) Among the four factors, the contribution of the energy intensity effect to increasing CO_2 emissions was greatest, and energy intensity increased in about half the prefectures. In addition, the impact of the carbon intensity effect on emissions change was much lower than the other factors, although it reduced overall emissions.
3) Among the eight industrial sectors, the *chemistry* and *metal* sectors were the two most influential in emissions changes in most prefectures.
4) In the *chemistry* sector, a greater number of prefectures had positive carbon intensity and structure effects, and a negative energy intensity effect. In the *metal* sector, a greater number of prefectures had negative carbon intensity and structure effects, and a positive energy intensity effect.
5) In Ibaraki and Chiba, the contributions of the *chemistry* and *metal* sectors to emissions changes were large and positive, whereas the contributions were spread across all sectors in Kumamoto.

The *chemistry* and *metal* sectors were the main causes of CO_2 emissions increases from the manufacturing industry between 1990 and 2013, with positive changes for each factor. Thus, reducing the factors from these sectors and making them negative will be essential if emissions from the manufacturing industry are to reach the reduction targets of the Paris Agreement and to be decreased further in the long term. Because increases in GPP contribute to economic development, the priority for emissions reduction is to address carbon and energy intensity. In relation to the *chemistry* and *metal* sectors, some prefectures were found to have decreased their carbon and/or energy intensity during the study period. Thus, the diffusion of technology and knowledge regarding the reduction of carbon and energy intensity has assisted in emissions reduction of these two sectors, and it is considered the same for other sectors.

From the perspective of local government, as exemplified by the case of Chiba, the setting of targets is considered an important approach for improving carbon and energy intensity. Such targets provide incentives for firms that could result in the emissions reduction. Thus, climate and energy policies adopted by local governments, not only in Japan but also in other countries, could contribute to emissions reductions of the manufacturing industry.

Local governments could also play a role in organizing "industrial symbiosis." This is a concept intended to improve energy and resource efficiency in the manufacturing industry, which is defined as engaging "traditionally separate industries in a collective approach to competitive advantage involving physical exchanges of materials, energy, water, and/or by-products" (Chertow, 2000). Because power plants and energy-intensive industries such as the *chemistry* and *metal* sectors have considerable potential to waste heat, their energy efficiencies could be improved by involving other industry sectors in the surrounding area via industrial symbiosis (Shiraki et al., 2016; Wu et al., 2016). In Japan, the city of Kawasaki in Kanagawa Prefecture achieved carbon emissions reductions of 13.8% through collaboration among stakeholders from the *metal*, *cement*, and *pulp and paper* sectors (Dong et al., 2014). Although traditional industrial symbiosis has developed spontaneously, some studies have indicated the importance of policy support by national and/or local governments for systematic expansion of industrial symbiosis (Park et al., 2008; Wu et al., 2016). Although the Government of Japan provides support policy for industrial symbiosis complexes such as the Eco-town Program (Ministry of the Environment, 2015) and the Smart-community Program (Gao et al., 2016), collaboration among the various industries has not been stimulated sufficiently. Local governments could accelerate industrial collaboration if our results (i.e., the critical factors of increases/decreases in emissions at sectoral level in each prefecture) were used to enhance their understanding of the local industrial community.

This study could be extended to analyze the factors affecting emissions changes by prefecture in other sectors, e.g., the household, transportation, and service sectors. In addition, integrated analysis of entire sectors at the prefectural level, including energy transformation, will be important to further the understanding of how CO_2 emissions change in Japan and to support the development of mitigation measures intended to achieve the emissions reduction target of the Paris Agreement.

APPENDIX A: PREFECTURES IN JAPAN

This appendix shows the geographic locations of the 47 prefectures in Japan (Figure A1).

Figure A1: Geographic locations of the 47 prefectures in Japan.

Notes: The circled prefectures are those used as case studies in section 3.2.

APPENDIX B: SECTORAL CO_2 EMISSIONS AND ENERGY CONSUMPTION

This appendix shows the sectoral CO_2 emissions and energy consumption in Japan (Table B1). CO_2 emissions in the table correspond to Figure 1.

Table B1: Sectoral CO_2 emissions and energy consumption in Japan in 1990 and 2013

	1990		2013	
	CO_2 (ktC)	Energy consumption (PJ)	CO_2 (ktC)	Energy consumption (PJ)
Manufacturing	86781.2	6349.9	85512.6	5950.1
Service	20635.8	1788.8	19165.1	2531.0
Transportation	55281.1	3048.1	59462.1	3235.0
Household	15918.0	1683.0	15725.5	2012.2
Energy conversion	130760.7	6178.0	181843.8	6991.8
Agriculture and others	10634.2	670.2	4599.2	280.8
Total	**320011.1**	**19718.1**	**366308.2**	**21000.9**

Source: Agency for Natural Resources and Energy (2017b).

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