Decomposition analysis of Japan’s CO$_2$ emissions

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Abstract. Studies have been conducted to uncover the underlying factors of global CO$_2$ emissions. One method to quantify the driving forces of carbon dioxide emissions is decomposition analysis. In this paper, the logarithmic mean Divisia index (LMDI) method was used to investigate the driving forces of carbon dioxide emissions in Japan for the period of 1990-2017. As one of the world’s leading economies, it also contributes one of the highest CO$_2$ emissions globally. Results highlighted the flaw of energy structure as one major factor affecting CO$_2$ emission intensity. Another notable finding is how the state of the economy played a pivotal role in the shift of carbon emission levels. Potential policy recommendations were also introduced to establish a better power structure for electricity generation in the country.

1. Introduction

As one of the world’s leading economies, Japan had a nominal gross domestic product (GDP) of 5.15 trillion US dollars in 2019. It currently ranks third in terms of global economy and was projected to have a 0.7% growth in 2020 [1]. However, this economic development is countered by the country’s contribution to the global CO$_2$ emissions. In 2019, Japan is the fifth largest contributor of CO$_2$ emissions worldwide [2]. As part of its initiative to mitigate its carbon emissions, Japan was one of the countries who ratified the Paris Agreement in 2016. In line with this, Japan vowed a 26% reduction of its greenhouse gas (GHG) emissions by 2030, as compared to its 2013 levels [3].

Several studies have already been conducted to mitigate carbon dioxide emission by investigating its driving factors. Most of these researches have employed the use of decomposition analysis to unravel the factors affecting CO$_2$ emissions. For instance, a study was conducted using structural decomposition analysis (SDA) to investigate the source of changes of CO$_2$ emissions in the United States [4]. A similar method was used to analyze how changes in demographics, industry structure, and urbanization drive regional CO$_2$ emissions in China [5]. Moreover, a paper also delved into the driving factors of emissions from all European Union countries due to electricity generation [6], while an identical approach was employed to analyze the efficiency of policies relating to carbon emissions adopted in Italy [7]. Meanwhile, a study using logarithmic mean Divisia index (LMDI) was presented to examine the carbon emission trends in the iron and steel industry in Mexico [8], whereas the same method was used to study the change in energy-related CO$_2$ emissions in China’s industrial sector [9].

Other papers also used decomposition analysis to analyze CO$_2$ emission intensity in Japan. For example, a study used structural decomposition analysis to uncover the factors affecting the carbon emissions from the Japanese industry in 1985-1995 [10]. Another work evaluated the elements driving Japan’s CO$_2$ emissions using input-output SDA for the periods 1995-2000 and 2000-2005 [11]. Also, a paper merged financial factors in formulating its identity function for a decomposition analysis of the CO$_2$ emissions from the Japanese manufacturing sectors [12].
In this study, the LMDI decomposition analysis method is used to investigate the driving forces of carbon dioxide emissions from Japan for the period of 1990-2017. While other approaches have been used in decomposition analysis, the LMDI method is preferred for its general advantages. This approach is easy to use in terms of calculation and data requirements, and its results are easy to interpret for policymakers [13]. Furthermore, it has the capability to deal with indicators having a value of “zero” and perhaps, its most desirable characteristic is its perfect decomposition – no residuals or unexplained quantities.

The rest of the paper is organized as follows: the LMDI methodology is discussed in the next section, together with the data sources; the results and significant findings are discussed in Section 3; lastly, the conclusion and possible policy recommendations are given in Section 4.

2. Methods and data

2.1. LMDI decomposition analysis

Index decomposition analysis (IDA) was first employed to investigate electricity consumption trends and has since been widely used in energy-related research. An in-depth review of this methodology as an approach in energy analysis and policy making is provided in the paper by Ang and Zhang [14]. Moreover, it is reported that the logarithmic mean Divisia index (LMDI) decomposition analysis is regarded as the most popular IDA method; being used in the majority of index decomposition analysis papers published in 2010-2014 [15].

The LMDI approach uses the Divisia index and logarithmic mean weighted value to decompose aggregate indicators such as energy consumption. It can either be classified as additive or multiplicative decomposition. In additive decomposition analysis, the arithmetic change in the quantity between two given points in time is decomposed [16]. On the hand, multiplicative decomposition analysis decomposes the ratio change of an aggregate with respect to the baseline year [17].

2.2. Identity function

The decomposition analysis identity used in this paper is based on the function (Eq (1)) provided by Kaya, which established the connection among human population, GDP per capita, energy intensity, and carbon intensity [18]. Furthermore, the identity function used was adapted from Sumabat et al. [19], as given in Eq (2). The annual contributions of each individual effect were solved using Eqs (3) to (6), where \( C \) refers to the CO\(_2\) emissions, \( P \) signifies the human population, \( Q \) is the gross domestic product (GDP), \( E \) is for the energy usage, and \( i \) is the fuel type used to generate energy. In addition, \( G \) refers to GDP per capita, \( I \) is the energy intensity, \( S \) is shared in energy mix for fuel type \( i \), and \( F_i \) is emission factor for fuel type \( i \).

\[
\begin{align*}
\text{CO}_2 &= P \times \frac{\text{GDP}}{P} \times \frac{E}{\text{GDP}} \times \frac{\text{CO}_2}{E} \\
C &= \sum_i C_i = \sum_i P \times \frac{Q}{P} \times \frac{E_i}{E} \times \frac{C_i}{C} = \sum_i P \times G \times I \times S_i \times F_i \\
\Delta C_{\text{pop}}^\tau &= \sum_i \frac{C_i^T - C_i^0}{\ln C_i^T - \ln C_i^0} \ln \left( \frac{P^T}{P^0} \right) \\
\Delta C_{\text{act}}^\tau &= \sum_i \frac{C_i^T - C_i^0}{\ln C_i^T - \ln C_i^0} \ln \left( \frac{G^T}{G^0} \right) \\
\Delta C_{\text{int}}^\tau &= \sum_i \frac{C_i^T - C_i^0}{\ln C_i^T - \ln C_i^0} \ln \left( \frac{I^T}{I^0} \right) \\
\Delta C_{\text{str}}^\tau &= \sum_i \frac{C_i^T - C_i^0}{\ln C_i^T - \ln C_i^0} \ln \left( \frac{S_i^T}{S_i^0} \right)
\end{align*}
\]
The notation $\Delta C$ refers to the change in the emission levels from the baseline year, represented by the superscript 0, and the final year, represented by the superscript T, in that time interval. The subscripts $i$, $pop$, $act$, $int$, and $str$, refer to the fuel type, population effect, activity effect, intensity effect, and structure effect, respectively.

### 2.3. Data sources

The data used in this paper were taken from various sources. Japan’s data for its population, along with its gross domestic product (GDP) in constant 2010 USD, were sourced from the database of the World Bank [20]. On the other hand, the figures for Japan’s energy generation by source, electricity consumption by sector, and CO$_2$ emissions by sector, were obtained from the records of the International Energy Agency (IEA) [21].

### 3. Results and discussion

#### 3.1. Activity effect ($\Delta C_{act}$)

Shown in Figures 1 and 2 are the summary of the changes in the CO$_2$ emission levels of Japan. The aggregated effects depicted in Figure 1 shows that the carbon emissions of Japan have been increasing at an average rate of approximately 19,650 ktons of CO$_2$ per year interval from 1990-2007. However, a significant decrease can be noted starting from 2008 up to the year of 2009, where a noticeable decline in the activity effect ($\Delta C_{act}$) can be observed. Furthermore, looking at Figure 2, where the annual effects of CO$_2$ emissions is illustrated, it is shown that the activity effect has mostly been on the positive part of the graph, for the 1990-2007 period, indicating the contribution of the effect of economic activity in the emission levels. Nevertheless, a sharp turn of the activity effect into the negative region of graph is shown in the 2007-2009 period. The behavior of $\Delta C_{act}$ during the period 2007 to 2009 can be attributed as an effect of the Great Recession – an economic downturn after the global financial crisis.

![Figure 1](image1.png)

**Figure 1.** The aggregated CO$_2$ emissions level from various driving factors (1990-2017)

Elaborating, the global financial crisis refers to the extreme stress in the global economy in the period of mid-2007 to 2009 [22]. During this timeframe, major economies in the world experienced the worst recessions since the 1930 Great Depression, and many banking institutions depended on government support to prevent bankruptcy. In Japan, it caused a major collapse in the movement of exports and industrial productions [23], leading to its record high steepest fall in GDP at 15.2% since 1955 [24], thereby affecting the economic activity, and by extension, the share of activity effect in its CO$_2$ emissions.
3.2. Structure effect ($\Delta C_{str}$)

On the other hand, Japan has a very diverse energy mix as shown in Figure 3. While it taps other energy generating facilities, the country is heavily dependent on zero emission nuclear power and emission intensive fossil fuels to address its energy demands. However, this will cause further serious implications as the country experienced one of the most disastrous calamities of the 21st century.

The 2011 Tōhoku earthquake and tsunami devastated the Pacific Coast of Japan causing immense casualties and damages, including the subsequent meltdown of the Fukushima Daichi Nuclear Facility [25]. It was followed by a massive shutdown of nuclear facilities all over Japan amidst the fear of further nuclear disaster [26]. The 2010-2012 trend in the structure effect ($\Delta C_{str}$), as shown in Figure 2, is a consequence of the nuclear shutdown. As Japan has been left with no nuclear-derived electricity for the first time in 42 years, the country shifted towards cheaper, yet emission intensive fossil fuel-based facilities.

Moreover, in the 2010-2012 timeframe, the $\Delta C_{str}$ amounted to approximately 134,883 ktons of CO$_2$, the largest contribution of all the 4 quantified effects in the 1990-2017 study period. This is after the fact that Japan imported an estimated 30,000 barrels a day more of fossil fuels in 2011, and a further
80,000 barrels per day more than its usual consumption in 2012, to compensate for the loss of its nuclear-sourced energy generation [27].

3.3. Intensity effect ($\Delta C_{\text{int}}$)
The intensity effect ($\Delta C_{\text{int}}$) in Japan’s CO$_2$ emissions took a drastic constant change from 2010 onwards as shown in Figure 2. From an aggregated share of approximately 5,380 kton of CO$_2$ emission in the 2009-2010 period, it plummeted into the negative region of the graph in 2010-2011 period and has since been at an average yearly decline of 63,200 ktons of CO$_2$. Three factors can then be considered as plausible driving factors for this behavior of a quantified effect. First, the 2011 Tōhoku earthquake and tsunami prompted an energy crisis in Japan. Even with the production adjustment of manufacturing industries to save electricity, the Japanese government also mandated a reduction in electricity consumption in 2011 and 2012, aside from the rolling blackouts for several hours that were experienced in the first month after the disaster [28]. Another factor to be considered is that Japanese industries continually expand their overseas manufacturing operations. A survey report conducted by the Japan Bank for International Cooperation (JBIC) for the fiscal year of 2017 indicated that the overseas production ratio of Japanese manufacturing companies was at 35% in 2016 and is projected to increase up to 38.5% by 2020 [29]. Lastly, the constant increase of contribution of the services sector in Japan’s gross domestic product (GDP), as shown in Figure 4, is also a factor worth considering. Additionally, it is reported that the country’s capital expenditure is gearing towards the services sector and has risen to 9.2% mid-2018 [30].

![Figure 4](image)

**Figure 4.** Gross domestic product (GDP) contribution per sector (1994-2017)

3.4. Population effect ($\Delta C_{\text{pop}}$)
The contribution of population growth to CO$_2$ emission levels remained positive ($\Delta C_{\text{pop}}$) all throughout the 1990-2008 period, as shown in Figure 2. However, this behavior has changed from 2009 onwards, as Japan is currently experiencing a population crisis, due to a rapid decline in its population brought about by low fertility rates and an aging population. As of 2019, more than 20% of the Japanese populace is over 65 years old and its trend in fertility rates is heavily affected by various factors such as changing lifestyles, marriage dilemma, and economic insecurity of the present generation [31].
4. Conclusion and recommendation

4.1. Policy recommendation

Based on the presented data and analysis of the results, stated below are the recommendation options that the policy makers can explore:

1. Japan needs to ease its dependence on nuclear energy as its main energy source to prevent further energy crises that followed the 2011 nuclear disaster. More secure alternatives need to be explored.
2. In accordance with the previous recommendation, Japan can increase investment on renewable energy as a potential alternative to nuclear power.

The Great East Japan earthquake of 2011 exploited a weakness in Japan’s energy security. Its heavy dependence on nuclear energy, amounting up to 31.3% before the disaster, proved to have serious implications. Moreover, the public perception on nuclear power has also been affected and protests against further use of nuclear energy were initiated as a yearning for a “zero nuclear power operation”. Thus, the country needs to establish a better power structure in electricity generation. The barely tapped potential of renewable energy sources in the country is one probable solution to this problem. According to Japan’s Ministry of the Environment in 2011, around 887 gigawatts (GW) of energy can be economically exploited in the country. It is almost 4 times the combined installed capacity of nuclear facilities and conventional thermal power plants in Japan in that period. In conclusion, since the energy structure has been the highlight of the study, planning of the best energy mix is key for a sustainable and energy-secure Japan.

4.2. Conclusion

This paper used the logarithmic mean Divisia index (LMDI) decomposition analysis to uncover the driving factors of carbon emission intensity in Japan. Particularly, this study focused on identifying specific strategies adopted by Japan to mitigate its CO₂ emissions, considering its unique economic and resource limitations. Results indicated that economic activity had a significant impact in the shift of CO₂ emissions level. Moreover, the energy mix of Japan for the 1990-2017 period was placed under scrutiny. Based on the analysis of data, Japan’s energy structure needs to be diversified with more secure alternatives to alleviate its dependence on nuclear power. Potential policy recommendations were also given and discussed to ensure the country’s energy security.

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