Using Logarithmic Mean Divisia Index method (LMDI) to estimate drivers to final energy consumption and emissions in ASEAN

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Abstract. The ASEAN is currently trying to mitigate the amount of CO₂ emissions per country. This is not only to contribute to the worldwide goal of lessening greenhouse gases, but to also ensure the safety of its member states by combatting the effects of climate change. The effects as stated by the IPCC, such as rising water levels, rising ambient temperature, and an increase in the frequency of tropical storms, can greatly endanger members of the ASEAN. It must be noted that a majority of its members are archipelagic, have areas of extreme poverty, and rely on agriculture for production. Therefore, the temporal logarithmic mean Divisia index (LMDI) has been conducted in order to determine the possible drivers that cause the changes in CO₂ emissions per year for all ASEAN member countries. The drivers of CO₂ were divided into the population, economic activity, energy intensity, and energy structure effects. CO₂ emissions per fuel type were calculated using their respective emission factors. Knowing which drivers constitute the most CO₂ emissions in a country would help pinpoint which areas could be worked on. It was found that Indonesia, Brunei Darussalam, and Lao PDR had the most impressive decrease in CO₂ emissions due to energy intensity and structure effects. A majority of the other countries have either stayed constant or even increased CO₂ emission output per year from each effect. Therefore, general policies based on the success of these countries that could be applied for each member country are recommended in this study.

1. Introduction
The Association of Southeast Asian Nations (ASEAN) is a collection of 10 countries that was established back in the 8th of August, 1967. One of the main purposes of the ASEAN is to accelerate and promote economic growth and cultural development within the region. It is also meant to promote active support and collaboration between its member countries in the areas of economics, science, culture, and education [1]. The members are Indonesia, Malaysia, Philippines, Singapore, Thailand, Brunei Darussalam, Vietnam, Lao PDR, Myanmar, and Cambodia. Outlined in the Treaty of Amity and Cooperation in Southeast Asia (TAC), the ASEAN was built upon the promise of continued support and unity between its nations, while maintaining mutual respect for their individual independence, territory, and national identity.

Climate change is a growing problem that can greatly affect countries and regions all around the world. As addressed in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), the increase in average air and ocean temperatures, along with the melting of the polar ice caps, indicate the global warming effect [2]. This effect is then accelerated by the emission of
greenhouse gases such as carbon dioxide, methane, and nitrous oxide. It was only in 2014 when the Fifth Assessment Report of the IPCC determined that the main driver for climate change was carbon dioxide [3]. The IPCC has projected that without preventative measures, the global average temperature will rise from 1.8 to 4 degrees Celsius, and that there will be a rise in sea levels by about 18 to 59 centimetres. The occurrence of natural disasters such as typhoons, heat waves, floods, and droughts will become more frequent as well.

Given that the ASEAN members are generally located to the west of the Pacific Ocean, and that a number of its members are archipelagic states, the effects of climate change will become more apparent and devastating if preventative measures are not implemented. Additionally, the region has areas of extreme poverty, and that the people are heavily reliant on agriculture. A study from Nunti et al. has proven that climate change has an overall negative effect on agricultural areas using the copula-based stochastic frontier approach [4]. This constitutes not only an escalated vulnerability to natural disasters, but also an increased risk for numerous communities in terms of livelihood and survival. For example, Typhoon Vamco has hit the Philippines, an archipelagic country, in November 2020. This caused massive flooding and displaced numerous communities, resulting in around 102 deaths and 402 million dollars in damages [5]. Another example would be the Central Vietnam Floods that was caused by a number of seasonal monsoons and tropical depressions. The country was also affected by Typhoons Goni and Vamco, resulting in 233 fatalities and about 1.52 billion dollars in damages.

Throughout the years the ASEAN nations have collaborated on many programs that addressed climate change. This is done not only to mitigate the loss of life and property, but also to contribute to the overall goal of decreasing CO₂ emissions in the world. For example, Indonesia has volunteered to reduce emissions by 26% to 41% by the end of 2020. Given the same deadline, Malaysia has also pledged to reduce emissions by 40%, Philippines by 20%, and Singapore by 16% [6]. Given the evident dangers of climate change, especially its devastating effects on the ASEAN region, as well as the ever-increasing carbon dioxide emissions, this study aims to estimate the drivers for CO₂ emissions in the ASEAN region. Additionally, historical data such as past policies and laws will be discussed in order to determine their efficacy in mitigating carbon dioxide emissions. This study aims to not only highlight the most effective policies that were enacted, but also infer and derive other possible policies based on the collated data.

Decomposition analysis will be used to study the acquired data, as this method is most commonly used to determine drivers that cause significant changes in terms of environmental impact and energy over time [7]. This method can then be divided into structural decomposition analysis (SDA) and index decomposition analysis (IDA). SDA is most commonly used for studying the impacts brought on by the consumption of a particular indicator, while IDA is meant for studying the impacts of producing a particular indicator. It must be noted that decomposition analyses have already been conducted by previous studies. For example, a study by Sumabat et al. conducted a decomposition analysis using the logarithmic mean Divisia index method (LMDI) to determine CO₂ emissions from the consumption of fuel and generation of electricity in the Philippines [8]. Another study also used the LMDI method based on energy allocation to determine drivers of CO₂ emissions in Malaysia [9].

The paper will utilize IDA, particularly the logarithmic mean Divisia index method to estimate drivers that caused the biggest change in CO₂ emissions from 2010 to 2017 due to the final consumption of each ASEAN country. The CO₂ emissions will be calculated using the fuel type consumed by the industries of a particular country in a particular year. This study will be organized as follows: the equations, discussion, and data will be provided in Section 2; the results will be presented in Section 3; and the conclusions and proposed policies will be discussed in Section 4.

2. Methods and Data

2.1. Fuel Consumption per Country

As stated earlier, the amount of fuel consumed by all 10 countries was taken from the International Energy Agency (IEA). The final industrial energy consumption (excluding power generation) by a country has been further divided into 8 types; namely coal, crude oil, oil products, natural gas, nuclear,
hydro, biofuels and waste, and wind and solar. The consumption of each fuel type per year from 2010 to 2017 was gathered in order to estimate the amount of carbon dioxide released after use. Figure 1 below shows the final industrial consumption for each type in the whole ASEAN.

![ASEAN Fuel Consumption](image)

**Figure 1. ASEAN percent share in industrial fuel consumption from 2010 to 2017**

2.2. $\text{CO}_2$ Emissions per Country

The annual carbon dioxide emissions per fuel type was calculated using Eq. 1 below, where $C$ is the $\text{CO}_2$ emissions in kilotons of $\text{CO}_2$ (kt$\text{CO}_2$); the subscript $i$ stands for the fuel type; the superscript $j$ refers to the year; $A$ is the amount of fuel $i$ consumed in kilotons of oil equivalent (ktoe) in the year $j$; and $EF$ is the emission factor for a particular fuel type $i$. The $EF$ was converted to kt$\text{CO}_2$ per ktoe using the units in Table 1 below.

$$C^i_j = A^i_j EF^i_j \quad (1)$$

The emission factors used for the corresponding fuel types are summarized in Table 1. It must be noted that there are no emission factors for nuclear, hydro, wind, solar, and biofuels. Biofuels were treated to be carbon-neutral in this study. Additionally, a majority of the countries have not used particular fuel types at all. In order for the LMDI to work however, small values of about $1 \times 10^{-6}$ ktoe were substituted instead.

| Fuel Type                  | Fuel Combustion | Units       |
|----------------------------|-----------------|-------------|
| Coal                       | 965$^a$         | t$\text{CO}_2$/GWh |
| Crude Oil                  | 74.54$^b$       | kg$\text{CO}_2$/mmBtu |
| Oil Products               | 161.3$^c$       | lb$\text{CO}_2$/mmBtu |
| Natural Gas                | 117$^c$         | lb$\text{CO}_2$/mmBtu |
| Nuclear                    | N/A             | -           |
| Hydro                      | N/A             | -           |
| Wind, Solar, Etc.          | N/A             | -           |
| Biofuels and Waste         | N/A             | -           |

*a Sources: [10]

*b Sources: [11]

*c Sources: [12]

2.3. Index Decomposition Analysis

As stated earlier, the logarithmic mean Divisia index Method was used in order to determine the drivers of $\text{CO}_2$ emissions in the ASEAN region. A paper by Ang provided a practical tutorial to setting up the needed formulas and steps in conducting the method [13]. To begin with, the aggregate must first be determined, which in this case was the total $\text{CO}_2$ emissions denoted as $C$. Next, the IDA identity function must be outlined, shown in Eq. 2 below. In doing so, it is important that the function must equal the aggregate to be studied, namely $C$. The variables used in the identity must pertain to the economic activity of a country with respect to its energy usage. Therefore, $P$ refers to the population, $G$ is gross domestic product (GDP), and $E$ is the amount of fuel used where $i$ is the fuel type. Once simplified, $M$
is the GDP per capita, \( I \) is the energy intensity in ktoe per GDP, and \( S_i \) is the share in energy mix for a particular fuel type \( i \).

\[
C = \sum_i C_i = \sum_i P \times \frac{G}{E} \times \frac{E_i}{E} \times \frac{C_i}{E_i} = \sum_i P \times M \times I \times S_i \times EF_i \tag{2}
\]

Given that the LMDI used in this study was based on the change of certain drivers over the years, it must be noted that certain effects can take on negative values. A negative effect simply means that the CO\(_2\) emissions from a particular fuel type in that year was lower than the last, and vice versa. The sum of a particular effect from the baseline year to the final year dictates the overall influence of that effect to the CO\(_2\) emissions.

The effects used in this study were namely; the population effect (\( \Delta C_{pop} \)), the economic activity effect (\( \Delta C_{act} \)), the energy intensity effect (\( \Delta C_{int} \)), and the structure effect (\( \Delta C_{str} \)). The population effect referred to the contribution of the increase or decrease in the country’s population, and it was calculated using \( P \). The economic activity effect referred to the change in the economic activity, measured in million USD per capita or \( M \) in the IDA identity. The energy intensity effect referred to the net increase or decrease in the needed energy to produce the same amount of product. It was measured in ktoe per million USD, or \( I \). Any decrease in the energy intensity means that the production process has either gotten more efficient or there has been a change in production. Finally, the structure effect referred to the fuel changes adopted by the country after a year has passed. This was calculated using \( S_i \) in the IDA identity. Eqs. 3 to 6 show the formulas for each effect.

2.4 Data Gathering

The amount of fuel consumed by each country was taken from the International Energy Agency [14]. For consistency, the amount of fuel used was expressed in kilotons of oil equivalent. Other pertinent data such as the population and Gross Domestic Product (GDP) were taken from The World Bank [15]. It must be noted that the GDP was in terms of millions of USD, and that it was kept at a constant 2010 USD value for all countries in order to take inflation into account.

\[
\Delta C_{pop}^T = \sum_i \frac{C_i^T - C_i^0}{\ln C_i^T - \ln C_i^0} \ln \left( \frac{P^T}{P^0} \right) \tag{3}
\]
\[
\Delta C_{act}^T = \sum_i \frac{C_i^T - C_i^0}{\ln C_i^T - \ln C_i^0} \ln \left( \frac{M^T}{M^0} \right) \tag{4}
\]
\[
\Delta C_{int}^T = \sum_i \frac{C_i^T - C_i^0}{\ln C_i^T - \ln C_i^0} \ln \left( \frac{I^T}{I^0} \right) \tag{5}
\]
\[
\Delta C_{str}^T = \sum_i \frac{C_i^T - C_i^0}{\ln C_i^T - \ln C_i^0} \ln \left( \frac{S^T}{S^0} \right) \tag{6}
\]

3. Results and Discussion

3.1 Total CO\(_2\) Emissions per Country

After acquiring the amount of fuel consumed per country, the total CO\(_2\) emissions were solved using Eq. 1. The emission factors were simply converted to ktCO\(_2\) per ktoe. Figures 2a to 2j show the total CO\(_2\) emissions of each fuel type per country.

\[
\Delta C = \sum_i C_i = \sum_i P \times \frac{G}{E} \times \frac{E_i}{E} \times \frac{C_i}{E_i} = \sum_i P \times M \times I \times S_i \times EF_i \tag{2}
\]
Figure 2a. Indonesia CO₂ Emissions

Figure 2b. Malaysia CO₂ Emissions

Figure 2c. Philippines CO₂ Emissions

Figure 2d. Singapore CO₂ Emissions

Figure 2e. Thailand CO₂ Emissions

Figure 2f. Brunei Darussalam CO₂ Emissions

Figure 2g. Vietnam CO₂ Emissions

Figure 2h. Lao PDR CO₂ Emissions

Figure 2i. Myanmar CO₂ Emissions

Figure 2j. Cambodia CO₂ Emissions
As can be seen from the graphs above, the countries of Philippines, Vietnam, and Cambodia seem to stay consistent with the types of fuel being used. A majority of the carbon dioxide emissions from the industrial sectors of these countries come from the consumption of oil products and coal, with relatively small amounts of other fuel types. Indonesia, Malaysia, Thailand, Lao PDR, and Myanmar have been able to reduce their consumption of coal products as they transition to the use of oil products instead. Contrarily, Singapore can be seen transitioning to a small amount of coal from oil products in more recent years. Lastly, Brunei Darussalam has been recorded to have no dependence on coal.

In studying the drivers, Figures 3a to 3j are presented below. It can be seen that population and economic activity effects will always be positive contributors to CO\(_2\) emissions. However, all countries can be seen to have negative energy intensity and structure at certain years. A negative value is good, signifying that whatever policy or shift in energy use that was implemented in that year allowed the country to emit less CO\(_2\) compared to the previous year. It can be seen that Indonesia, Malaysia, Singapore, Thailand, Brunei Darussalam, and Lao PDR have achieved an impressive decrease in CO\(_2\) emissions in certain years. In contrast, the Philippines has produced more CO\(_2\) from energy intensity and structure effects. Additionally, the energy structure effects in both Vietnam and Cambodia seem to play a big role in their CO\(_2\) emissions despite having a negative and consistent energy intensity effect. Finally, a majority of Myanmar’s CO\(_2\) emissions stem from an excessively high energy structure effect.

Figure 3a. Indonesia CO\(_2\) Effects
Figure 3b. Malaysia CO\(_2\) Effects
Figure 3c. Philippines CO\(_2\) Effects
Figure 3d. Singapore CO\(_2\) Effects
Figure 3e. Thailand CO\(_2\) Emissions
Figure 3f. Brunei Darussalam CO\(_2\) Emissions
4. Conclusion and Policy Recommendations

From using index decomposition analysis, it can be seen that Indonesia, Brunei Darussalam, and Lao PDR have yielded the most impressive results. These countries were able to maintain the energy intensity at a constant negative effect in more recent years, and that CO$_2$ emissions were lessened by either maintaining or improving their energy structure.

To begin with, Indonesia has enacted a presidential regulation for a National Action Plan for Reducing Greenhouse Gas Emissions (RAN-GRK) that outlines the needed activities and policies for various institutions within the country to follow in order to reduce the amount of greenhouse gas (GHG) emissions in the year 2009 [16]. This is to follow-through with its promise of reducing greenhouse gases by 26% by the end of 2020. For this regulation, various factors were taken into account, such as national development priorities, feasibility, and sources of funding. Additionally, Brunei Darussalam has followed the Energy White Paper (EWP) in 2014. This set of policies published from the United Kingdom has set various regulations that use energy efficiency and conservation (EEC) initiatives to lessen CO$_2$ emissions in the energy sector [17]. Finally, Lao PDR has followed a series of policies that outlined its GHG emissions from 2010 to 2015 [18]. Some of these are the National Climate Change Strategy of 2010, the Renewable Energy Development Strategy of 2011, and the Climate Change Action Plan of Lao PDR in 2013, to name a few.

Taking from their example, it must therefore be noted that in creating the policies needed for all countries to be able to follow, certain actions that require the mitigation of GHG emissions need to be incentivized and fully supported by the government. Such methods can be done through:

1. Implementing tax and penalties to serve as a warning for industries and other sectors to maintain allowable GHG emissions.
2. Developing unique peer-reviewed standards and regulations that take into consideration the strengths of the country in terms of production, funding, and feasibility. These standards must be met by the different sectors of that particular country.
3. Actively campaigning the mitigation of GHG emissions. This can be done through informing the public and incentivizing citizens and businesses.
4. Promote research and development sectors to conduct studies that not only monitor the GHG emissions in their country, but to also develop more efficient and environmentally-friendly technology.
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