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Decomposition of Carbon Dioxide (CO_2) Emissions in ASEAN Based on Kaya Identity

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Abstract. ASEAN is a region with high carbon dioxide (CO_2) emissions, accompanied by an increase in population, gross domestic product (GDP) and energy consumption. Population, GDP, and energy consumption can be linked to CO_2 emissions through an identity equation called the Rich Identity. This research is based on Kaya identity to describe CO_2 emissions to calculate the impact of population, economic activity, energy intensity and carbon intensity on CO_2 emissions in ASEAN and 8 ASEAN countries (i.e., Indonesia, Malaysia, Singapore, Thailand, Philippines, Vietnam, Myanmar and Brunei Darussalam) from 1990 to 2017. The method used is the Logarithmic Mean Division Index (LMDI). The data used are from the International Energy Agency (IEA) and the World Bank. Four effects measured and main findings showed that population, economic activity and carbon intensity factor increased by 293.02 $MtCO_2$, 790.0 $MtCO_2$, and 195.51 $MtCO_2$, respectively. Meanwhile, energy intensity effect made ASEAN's CO_2 emissions decrease by 283.13 $MtCO_2$. Regarding contributions to the increase in CO_2 emissions in all ASEAN countries, the population effect increases CO_2 emissions in all countries in ASEAN and the economic activity effect is also the same, except in Brunei Darussalam which makes CO_2 emissions in this country decreased by 1.07 $MtCO_2$. Meanwhile, the effects of energy and carbon intensity are different. The effect of energy intensity causes CO_2 emissions in lower-middle income countries to decrease, while in upper-middle and high-income countries, it increases carbon emissions. In contrast to the effect of carbon intensity, that actually makes CO_2 emissions increase in lower-middle income countries and reduces carbon emissions in upper-middle and high-income countries.

Keywords: CO_2 emissions, Kaya identity, ASEAN, decomposition, LMDI

1. Introduction

The issue of global warming is one of the topics discussed in countries around the world. One of the causes of global warming is greenhouse gases (GHG). In the last 25 years of the 20th century, GHG in the atmosphere have increased significantly. This increase has had some inevitable consequences for our planet in terms of climate change and global warming. Carbon dioxide (CO_2) accounts for the largest share of the six major GHG and is the main accelerator of the greenhouse effect in the atmosphere. CO_2 emissions have increased rapidly, since fossil fuel combustion and human-based activities such as industrialization, agriculture, urbanization, lifestyle, international trade, are the main drivers of fossil fuel combustion (Hatzigeorgiou et al., 2008).

The ten countries in the ASEAN region have high CO_2 emissions. World Resource Institute–WRI (2019) reported that in 2016, the 10 ASEAN countries contributed 7.35% of the total CO_2 emissions of all countries in the world. Indonesia accounts for 5% of the world's total CO_2 emissions, or about 1841.14 MtCO2, Indonesia the fifth largest CO_2 emitter after Russia. As the ASEAN countries are currently in the process of industrialization, they need a lot of energy to support the industrial production process, so the level of CO_2 emissions in ASEAN will continue to rise. Energy use plays an important role in causing CO_2 emissions on the planet, as the energy sector produces 32,553.48 $MtCO_2$, accounting

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for approximately 73% of total CO_2 emissions (WRI, 2019). At the ASEAN level, the energy sector is the largest contributor. The energy sector became the largest contributor to ASEAN's CO_2 emissions from 2006 until now, with a contribution rate of 62% or approximately 1.3 $GtCO_2$ in 2017.

According to the International Energy Agency–IEA (2019), the global energy demand of ASEAN has increased by more than 80% between 2000 and 2018, and the use of fossil energy has doubled. Petroleum is the most critical element in the energy structure and coal has the fastest growth. These two types of energy support the development and growth of the industry, but they also cause water pollution, harm public health and generate energy-related CO_2 emissions. If the use of fossil energy is not reduced, emissions on the planet will never reduce.

Another factor that increases CO_2 emissions is population (Alam et al., 2016; Dong, 2018; Zhang & Tan, 2016). Human activities such as burning fossil fuels, deforestation and the production of chlorofluorocarbons (CFC) cause emissions. The increase in population will also increase the demand and supply of goods and services. Meanwhile, energy is an important production factor for industry to produce goods and services. Finally, to fill the growing demand for goods and services of the population, the use of energy leads to an increase in CO_2 emissions (Bongaarts, 1992; Ghazali & Ali, 2019; Lin et al., 2017).

ASEAN's population growth is classified as experiencing reasonably rapid growth. A report by the ASEAN Secretariat (2018) noted that the total population of the 10 ASEAN countries reached 642.1 million in 2017, almost double the size of 355.2 million in 1980. The average population of the ASEAN has increased by approximately 7.5 million people from 1980 to 2017. The annual population growth rate has fallen since the 1990s to about 1.2% in the last five years. Although the population growth rate is decreasing from year to year, the total population of ASEAN is still relatively large. This is because ASEAN has Indonesia, which is the fourth most populous country in the world.

Economic growth has an impact on the growth of CO_2 in a region. The concept between economic growth and CO_2 emissions can be explained in the hypothesis of the Environmental Kuznets Curve (EKC). This concept explains that environmental quality, which can be measured by CO_2 emissions, deteriorates in the early stages and increases in the next stages as the economy develops (Dinda, 2004). The EKC assumption does not always apply to all countries. Several studies in developing countries have shown that the EKC assumption has not been confirmed and that environmental degradation is directly proportional to economic growth (Al-Mulali et al., 2015; Farhani & Ozturk, 2015; Gill et al., 2018; Mikayilov et al., 2018).

In recent decades, ASEAN's economic performance has made significant progress. In 2017, the current gross domestic product (GDP) was close to 2.8 trillion U.S. dollars, and ASEAN has become the fifth largest economy globally and the third largest economy in Asia. The real GDP growth rate of ASEAN has been positive during 2000–2017. ASEAN's economic growth is primarily supported by the industrial sector, the largest contributor to CO_2 emissions in the region. Therefore, industrialization in many ASEAN countries can threaten the preservation of the environment and natural resources.

The relationship of energy consumption, population, GDP and CO_2 emissions are reflected in Kaya identity equation. Kaya identity is an identity equation which states that the total level of CO_2 emissions can be expressed as the product of four factors, namely population, GDP per capita, energy intensity (per unit of GDP) and carbon intensity (emissions per unit of energy consumed) (Kaya & Yokoburi, 1997). According to Kaya identity, CO_2 reduction can be obtained through three important factors, namely: (1) Population through the population itself and GDP per capita; (2) GDP through GDP per capita and energy intensity; (3) Energy through energy intensity and Carbon intensity consumption.

Kaya identities appears because another model that analyze factors that impact environmental quality such as Impact-Population-Affluence-Technology (IPAT) has several weaknesses. IPAT model is difficult to convert technological variables into units or to find a direct proxy (Giambona et al., 2005). On the other hand, in Kaya identity, technological variables are explained by two variables, energy

intensity and carbon intensity. Decreasing in energy intensity indicates that the technology used can improve energy efficiency. At the same time, the reduction in carbon intensity indicates that the energy used is environmentally friendly or generates fewer emissions.

Research on ASEAN often uses econometric methods that can only generate relation between variables, such as Heidari et al. (2015), Lean and Smyth (2010) and Saboori and Sulaiman (2013), who analyzed the relationship between CO_2 emissions, energy consumption and economic growth. Analysis by decomposing Kaya identity can determine how big the contribution of each factor This research aims to calculate and analyze the contribution of population, per capita income, energy intensity, and carbon intensity to CO_2 emissions in 8 countries in ASEAN, namely Indonesia, Malaysia, Singapore, Thailand, Philippines, Vietnam, Myanmar and Brunei Darussalam from 1990 to 2017 by decomposing Kaya identity.

Several studies have been conducted on the decomposition of Kaya identity, especially in countries with high CO_2 emissions. Li & Ou (2013), Ma et al. (2019), and Wang & Feng (2017) analyzed the Kaya identity of China's CO_2 emissions. Kaya identity is beneficial in finding the most effective and critical standards for implementing CO_2 reduction targets because it determines the driving force of CO_2 emissions from human activities (Tavakoli, 2018). Kaya identity decomposition studies are also often used to compare CO_2 emissions in the same region or countries with very different CO_2 emissions levels (Moutinho, 2015; Robalino López et al., 2016; Román Collado & Morales Carrión; 2018; Rüstemoglu & Andres, 2016).

2. Method and Data

The data used in this study are secondary data from the International Energy Agency (IEA) and the World Bank. Data on total emissions and total energy consumption are collected from the IEA. Then data on total GDP and population are obtained from the World Bank. The data period is from 1990 to 2017. Since the data is a time-series data, the Index Decomposition Analysis (IDA) method is considered. One of the commonly used in IDA methods is the Log Mean Dividing Index (LMDI). There are several advantages to using LMDI for decomposition analysis. According to Ang (2005), LMDI gives a perfect decomposition result, the result does not contain unexplainable residuals. Ang and Liu (2001) estimated that the effect at the subgroup level can be aggregated to produce corresponding effects at the group level, which means that LMDI is consistent in aggregation. Therefore, this research will use the LMDI method.

2.1 Decomposition Approach

The IPAT (Impact-Population-Affluence-Technology) model was first introduced by Ehrlich and Holdren (1971) which is used to analyze the factors that influence environmental quality.

$$I = P \times A \times T \tag{1}$$

The Equation (1) shows (I) impact is the result of the interaction of the total population (population/P), welfare (affluence/A) which is often expressed in real GDP per capita, and technology (technology/T) involved in supporting each unit of consumption (Giambona et al., 2005).

As the derivation of the IPAT equation, Kaya identity more specifically determines the various driving forces behind GHG emissions. These factors include demographics, economy, fuel type and energy use to estimate potential CO_2 emissions (Tavakoli, 2017).

$$C = P(Y/P)(TE/Y)(C/TE) \tag{2}$$

The Equation (2) can help determine the drivers of CO_2 emissions by breaking down CO_2 emissions into various drivers, namely population (P), GDP per capita (Y/P), energy intensity (TE/Y) and carbon intensity (C/TE) of energy use.

The model used in this study is derived from the Kaya identity, which divides CO_2 emissions according to the fuel source.

$$C = \sum_i C_i = P(Y/P)(TE/Y)(C_i/TE) = \sum_i PGIF_i \quad (3)$$

From the Equation (3) above, C, P, Y, and TE show the total CO_2 emissions, population, GDP and total energy consumption. The three ratios on the right side of the equation (Y/P, TE/Y, C/TE) represent GDP per capita (G), energy intensity (I) and carbon intensity from fuel (F_i).

This study uses the Additive LMDI approach to explain changes in CO_2 emissions. Additive LMDI shows the decomposition result in absolute value (according to the decomposition unit). From Equation (3), the difference in annual CO_2 emission levels can be explained by the following equation:

$$\Delta C_{tot} = C^t - C^0 = \Delta C_{pop} + \Delta C_{ypc} + \Delta C_{int} + \Delta C_{emc} \quad (4)$$

from the Equation (4), ΔC_{tot} is the total of population effect (ΔC_{pop}), economic activity effect (ΔC_{ypc}), intensity energy effect (ΔC_{int}) and carbon intensity effect (ΔC_{emc}).

The effects contained in Equation (4) can be calculated for each effect using the following equation:

$$\Delta C_{pop} = \sum_i \frac{C_i^t - C_i^0}{lnC_i^t - lnC_i^0} ln\left(\frac{P^t}{P^0}\right) \quad (5)$$

$$\Delta C_{ypc} = \sum_i \frac{C_i^t - C_i^0}{lnC_i^t - lnC_i^0} ln\left(\frac{G^t}{G^0}\right) \quad (6)$$

$$\Delta C_{int} = \sum_i \frac{C_i^t - C_i^0}{lnC_i^t - lnC_i^0} ln\left(\frac{I^t}{I^0}\right) \quad (7)$$

$$\Delta C_{emc} = \sum_i \frac{C_i^t - C_i^0}{lnC_i^t - lnC_i^0} ln\left(\frac{F_i^t}{F_i^0}\right) \quad (8)$$

where i represents the type of fuel, namely coal, oil, and gas, and t represents the time (in this study, t = 1990,..., 2017). Equation (5) to calculate the population effect (ΔC_{pop}), Equation (6) to calculate economic activity effect (ΔC_{ypc}), Equation (7) to calculate energy intensity effect (ΔC_{int}), and Equation (8) to calculate carbon intensity effect (ΔC_{emc}).

3. Results and Discussions

3.1 Results

Table 1 shows the results of Kaya identity decomposition using the Additive LMDI method. Based on this method, ASEAN CO_2 emissions increased by 996.76 $MtCO_2$ between 1990 and 2017, of which the impact of economic activities dominated the changes in CO2 emissions, 790.91 $MtCO_2$. Carbon intensity and population effects have increased ASEAN's CO2 emissions by almost the same amount, 195.51 $MtCO_2$ and 293.02 $MtCO_2$, respectively. Energy intensity effect reducing CO2 emissions in ASEAN by 283.18 MtCO2, and energy intensity in ASEAN has not been able to reduce CO2 emissions in ASEAN as a whole.

The impact of economic activity can be seen in all countries, except Brunei Darussalam. Rapid economic growth is one of the reasons for the increasing demand for energy and carbon emissions. Although this is not a linear relationship, production and consumption patterns in economies and

societies are inseparable from energy. ASEAN is also experiencing population growth, and even this impact has caused all ASEAN countries to experience increased carbon emissions. Population increase has been associated with the migration of labor and population to improve welfare. The carbon intensity effect increased during this period. This is because the use of fossil fuels still dominates the energy structure of ASEAN. At the same time, the energy intensity effect did not make any significant progress in reducing emissions in ASEAN during this period. The effect of reducing carbon emissions is not greater than the increase caused by the other three effects.

Table 1. Decomposition result 1990 to 2017 ($MtCO_2$).

Region	ΔC_{tot}	ΔC_{pop} ***(Population)***	ΔC_{ypc} ***(Economic activity)***	ΔC_{int} ***(Energy intensity)***	ΔC_{emc} ***(Carbon intensity)***
ASEAN	996.765	293.023	790.907	-283.182	195.508
Indonesia	362.200	111.846	274.520	-169.882	145.216
Malaysia	161.447	65.464	118.882	1.461	-24.293
Singapura	17.526	23.402	35.553	5.940	-47.370
Thailand	163.366	33.283	150.4588	15.380	-35.751
Filipina	88.439	36.022	52.932	-44.396	43.862
Vietnam	173.852	22.589	109.326	-23.984	65.969
Myanmar	26.486	2.270	19.803	-12.238	16.654
Brunei Darussalam	3.450	2.486	-1.066	5.294	-3.265

3.2 Population Effect

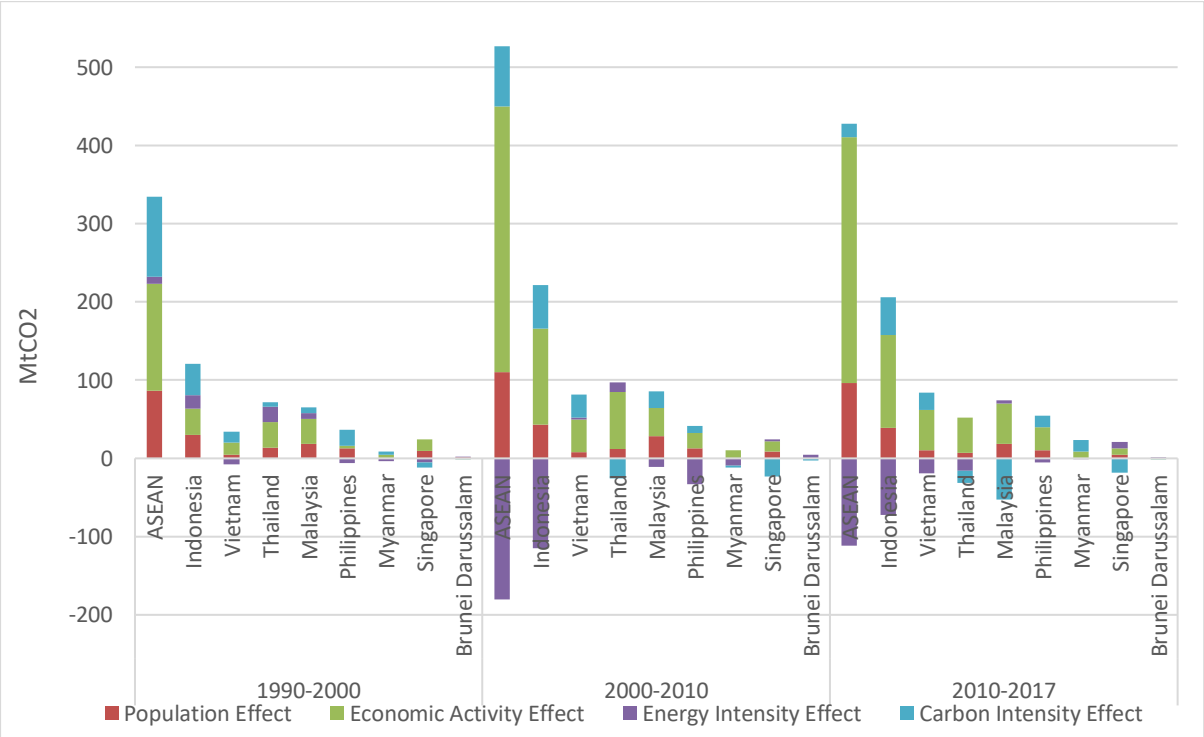


Figure 1. Decomposition result in three periods.

The impact of the population of ASEAN countries on CO_2 emissions has an impact on increasing CO_2 emissions. These results are similar to those found by Lima et al. (2016), Ma et al. (2019), Mahony (2013), Rüstemoglu and Andrés (2016), and Wang and Feng (2017). The number of ASEAN residents has led to an increase in CO_2 emissions, but this impact is not the largest contributor to the CO_2

emissions in these countries. Compared to the impact of economic activities, their contribution to increasing CO_2 emissions has decreased in each period, as shown in Figure 1.

The decline in their contribution is consistent with the ASEAN population growth that began to decline in the early 1970s. The decrease in population growth reflects the decrease in the total fertility rate (TFR) and negative migration values (Lima et al., 2016). The ASEAN TFR decline first occurred in Singapore in 1957, followed by Malaysia and Thailand in the mid-1960s, Indonesia and Philippines in the late 1960s and the TFR decline in Myanmar and Vietnam in the early 1970s. The decline increased sharply in the 1970s and early 1980s, eventually leading to a decline in the population growth rate. This is because since the 1970s, ASEAN countries have implemented policies to reduce births, especially in countries with large populations (Jones, 2014).

International immigration in developing countries such as Vietnam, Myanmar, Philippines and Indonesia greatly impact population growth. Workers in these countries choose to work and eventually settle abroad to improve family well-being (Jones, 2014). The marriage of women from ASEAN countries with men from Asian countries considered richer, such as Japan, South Korea and Taiwan, caused the international migration of these women, a phenomenon that increased rapidly in the 1990s (Chung et al., 2016).

3.3 Economic Activity Effect

The results show that, except for Brunei Darussalam, economic activities have an impact on the increase in CO_2 emissions of almost all ASEAN countries. These results are consistent with the results of Engo (2019), Ma et al. (2019), Mahony (2013), and Rüstemoglu and Andrés (2016). Except for Brunei Darussalam, the impact of economic activities is the main driving force behind economic growth in all countries. From 1990 to 2017, the impact of economic activities in several developing countries, including Indonesia, Vietnam, Philippines and Myanmar, has increased significantly.

In recent years, the economic development of developing ASEAN countries has been successful, characterized by rapid GDP growth. GDP growth is inseparable from the industrialization process. Industrialization requires a large amount of energy consumption, which leads to a substantial increase in CO_2 emissions. This can be seen in several developing ASEAN countries, where the rapid economic growth of these countries is consistent with the rapid growth of CO_2 emissions. The industrialization of Indonesia, Philippines, Vietnam and Myanmar was affected by government intervention. One of them is the Vietnamese government's efforts to encourage private trade and foreign direct investment (FDI), which resulted in the industrial sector accounting for 41% of Vietnam's total GDP in 2005, compared to 22% in 1988 and as high as 42.1% in 2010, Manufacturing is controlled by foreigners (Ahn et al., 2014). The concentration of manufacturing in Vietnam's industrial structure is one of the reasons for the increase in CO_2emissions, because the technology used still lags behind other countries (Ha, 2012). Similar to the first four countries, Malaysia and Thailand–which are middle-income countries–that economic activities led to increased emissions in both countries. The industrial sectors of Malaysia and Thailand still play a role in their economies. In 2018, this sector contributed 35% of Thailand's total GDP with a growth rate of 2.7%, while Malaysia's total GDP was 38.3% of the industrial sector, with a growth rate of 3.2% (World Bank, 2020).

This effect has reduced its contribution to increasing CO_2 emissions in Singapore, which is a high-income country. This is related to the economic structure of the country that pays more attention to the service sector. Deindustrialization is the main factor in balancing CO_2 emissions, especially for most developed countries (Yao et al., 2015). Singapore's economic growth is often greater than the growth in CO_2 emissions, and GDP growth is sometimes not accompanied by an increase in CO_2 emissions, as shown in Figure 2.

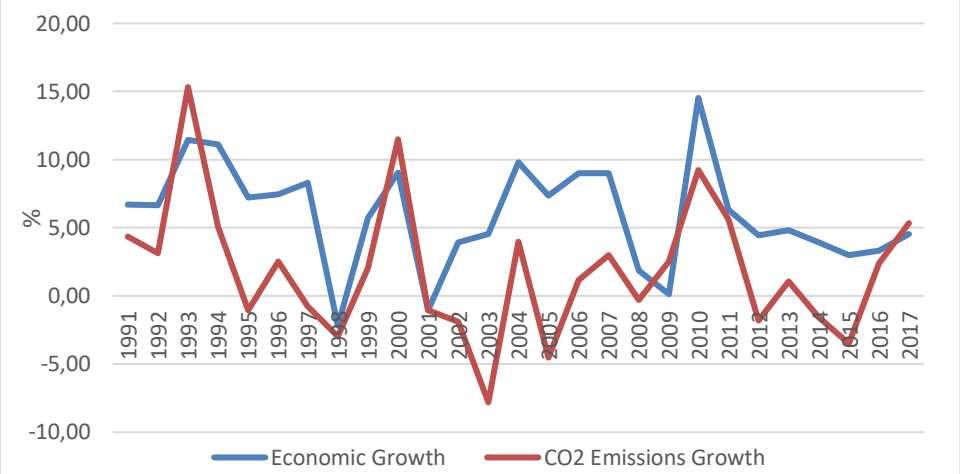


Figure 2. Singapore's economic growth & CO_2 emissions growth (International Energy Agency, 2019; World Bank, 2019).

Brunei Darussalam has achieved different results, in which the impact of economic activities has reduced CO_2 emissions. From 1990 to 2017, Brunei Darussalam's economic growth rate never reached 5%, even as from 2010, Brunei Darussalam's average economic growth rate had fallen by 0.2% per year (World Bank, 2019). Brunei Darussalam's dependence on its oil and gas resources has had an impact on economic growth. Ministry of Finance and Economy Brunei Darussalam (2019) reported that as from 2010, the mining industry had contributed an average of 46% of the total GDP, and the export of bulk commodities was still dominated by mineral products. Fluctuations in world oil prices have made Brunei's economy unstable, as declining oil production and a large amount of imported refined oil sent Brunei's economy into recession in 2013–2016. The economic recession has had an impact on CO_2 emissions. Since 2010, CO_2 emissions have been reduced by an average of 1.1% per year (International Energy Agency, 2019).

3.2 Energy Intensity Effect

Energy intensity is the main cause of CO_2 emission reduction in ASEAN and lower-middle income countries in ASEAN. These findings are similar to those of Engo (2019) in Cameroon, Ma et al., (2019) in China, Mahony (2013) in Ireland, and Román-Collado and Morales-Carrión (2016) in Latin America. The opposite situation occurs in the upper-middle and high income countries of ASEAN, and the energy intensity effect will affect the increase in CO_2 emissions of these countries. The results given are the same as those for France, that is, the country's intensity effect has an impact on the increase in CO_2 emissions from 1980 to 2010 (Yao et al., 2015).

Since the second period, there have been significant changes in the energy intensity effects of the lower-middle countries of ASEAN. This shows whether the technology and the efficiency of energy use have changed. The effects of energy intensity that occurred in the second and third periods are inversely proportional to the effects of economic activity. This means that during this period, economic reforms and improvements in production technology have increased industrial production and reduced energy intensity (Engo, 2019). Coal is one of the most widely used energy sources in ASEAN because, compared to other energy sources, Indonesia has abundant coal reserves, a relatively simple and low-cost mining process, and lower infrastructure requirements. Since the early 2000s, the use of coal in ASEAN has increased rapidly, with an average annual growth rate of 9% (International Energy Agency, 2019).

The impact of energy intensity in Malaysia and Thailand has different impacts in each period. In the first period, energy intensity increased the CO_2 emissions of both countries, while in the second period, energy intensity reduced Malaysia's carbon emissions but still affected the increase in CO_2 of Thailand.

On the other hand, in the third period, CO_2 emissions decreased due to energy intensity in Thailand and in Malaysia carbon emissions due to this effect increased by only 4.04 $MtCO_2$. This means that during the second and third periods, Malaysia and Thailand have been trying to improve their energy efficiency. Malaysia seeks to reduce 10% of final energy consumption of each sector from 2010 to 2030, and Thailand reduces energy intensity of the electricity sector by 30% by 2036 and 20% of final energy consumption by 2030 (Ministry of Energy Thailand, 2017; Prime Minister's Department Malaysia, 2010).

The overall results obtained in Singapore indicate that the effect of energy intensity increases CO_2 emissions. The contribution of increased energy intensity is inseparable from Singapore's energy use. In 2017, the use of oil doubled, from 7,942 Mtoe in 2008 to 18,973 Mtoe. Furthermore, Singapore is an importer of crude oil, and the price of crude oil was within the price range of USD 80/barrel to USD 120/barrel from 2010 to 2014 (Energy Information Administration, 2020). This means that the cost of energy consumption is also very high, leading to a decrease in Singapore's energy efficiency.

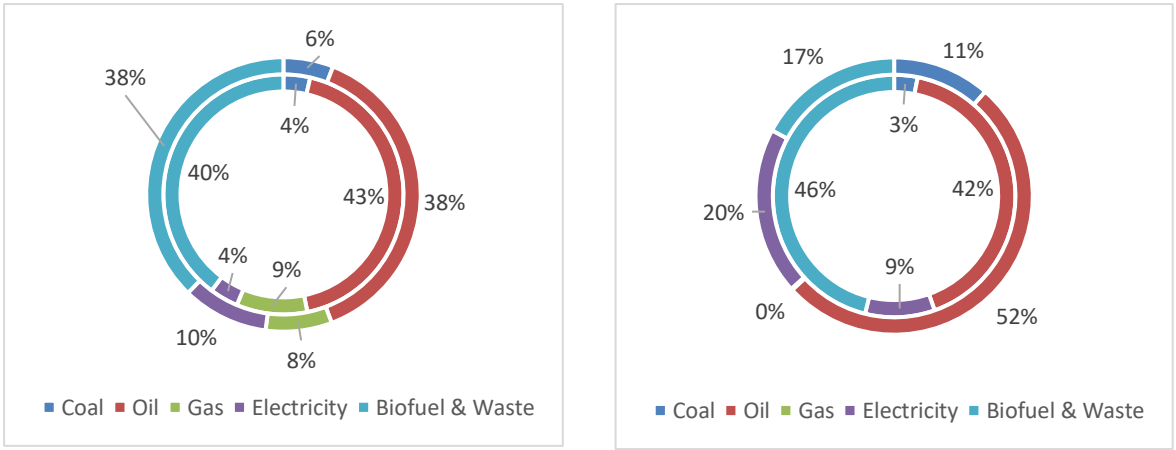
The impact of energy intensity is the main driver of growth in Brunei Darussalam's CO_2 emissions. These results indicate that Brunei Darussalam has not yet achieved energy efficiency. Brunei Darussalam's economy is supported by the mining sector, which is an energy-intensive sector. In the third period, the contribution of the energy intensity effect was lower than the 0.20 $MtCO_2$ of the previous period. Since 2014, Brunei Darussalam has been working hard to reduce energy intensity, reduce energy consumption by 65% by 2035, and increase tourism (Energy Department, 2014).

3.2 Carbon Intensity Effect

The decomposition results of this study show that the impact of carbon intensity increased ASEAN's CO_2 emissions in three periods. Indonesia, Vietnam and Philippines also achieved similar results, while Myanmar was only in the 2000-2010 period. The results are similar to research from Engo (2019) in Cameroon; Lima et al. (2016) and Rüstemoglu & Andrés (2016) in Brazil; Román-Collado & Morales-Carrión (2018) in Latin America; and Yao et al. (2015) in developing member states of the G20. Different results were found in Brunei Darussalam and Singapore. Both countries successfully reduced CO_2 emissions during all three periods of carbon intensity. Similar results were found in several studies conducted in high-income countries such as Cansino et al. (2015) in Spain; Lima et al. (2016) in England and Portugal; and Mahony (2013) in Ireland. At the same time, the carbon intensity effects of Thailand and Malaysia in the three periods did not always have a positive impact. Carbon intensity from 2010 to 2017 had a considerable impact on reducing CO_2 emissions in Malaysia, reducing 53.06 $MtCO_2$.

The different results of the ASEAN countries are inseparable from the energy consumption of each country. These results reflect the carbon content of the energy structure of each country. ASEAN developing countries, especially lower-middle income developing countries, have felt the negative impact of the energy intensity effect. These four countries are transforming their economic structures into industry-based economic structures. This makes the energy demand even higher and fossil energy is considered efficient because the costs incurred are relatively affordable. The energy structure of Indonesia, Philippines, Vietnam and Myanmar is still dominated by fossil energy.

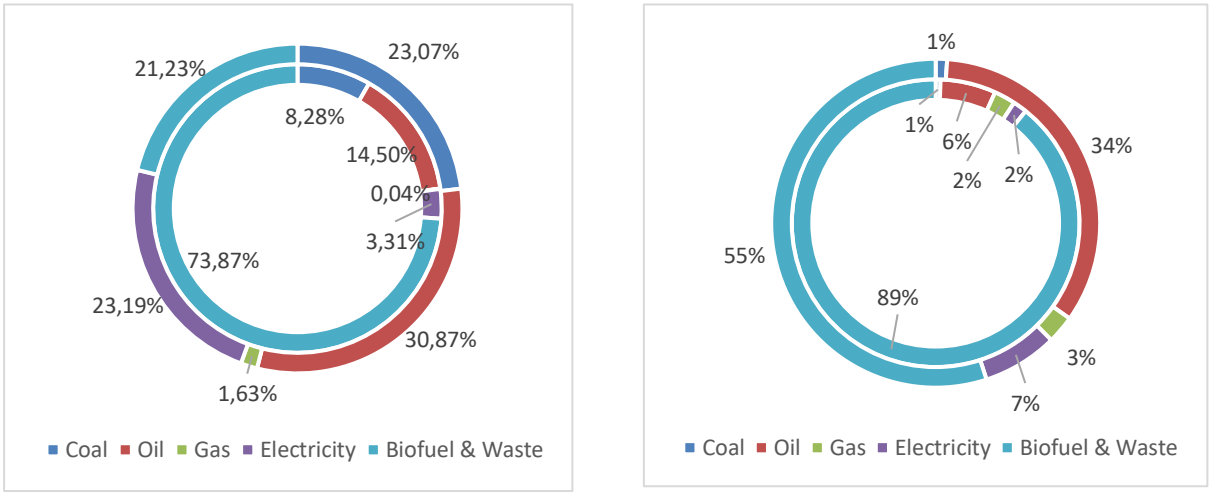
Figure 3 shows that oil use dominates the energy structure of Indonesia and Philippines, but among the three fossil fuels, coal has the fastest growth rate, especially in Philippines, where the average use of coal is 7% per year increase. Electricity contributes the most to the Indonesia's energy structure. In terms of generator types, steam power plants provide half of Indonesia's electricity capacity, and the electricity generated by steam power plants is increasing every year (Ministry of Energy and Mineral Resources, 2018). Although the amount of coal used is lower than oil, coal is still the main choice for power generation in Indonesia. The massive use of coal in both countries has led to a large increase in CO2 emissions because coal is the largest emitting fossil energy compared to oil and gas. The results show that the carbon intensity factor is highly dependent on the participation of fossil energy in the energy and electricity mix.



(a) (b)

Figure 3. Indonesia's energy mix (a) and Philippines's energy mix (b) (International Energy Agency, 2019).

Compared with the first two countries, Vietnam's energy mix is more equally, as shown in Figure 4(a). However, the growth of fossil energy is quite significant. The contribution of fossil energy consumption has risen rapidly from 22.37% in 1990 to 55.37% in 2017. In addition, Vietnam's power plants are still dominated by fossil energy. From 1990 to 2016, Vietnam's power generation grew at an annual rate of 12.8%, of which 38.9% of the power generation came from hydropower, 32.6% from coal, and 27.7% from natural gas (British Petroleum, 2018). Renewable energy and oil accounted for only 0.2% and 0.7% respectively. Tran (2019) estimates that, by 2050 fossil fuel consumption will reach 68.2% of total energy consumption, with coal dominating fossil fuel use.

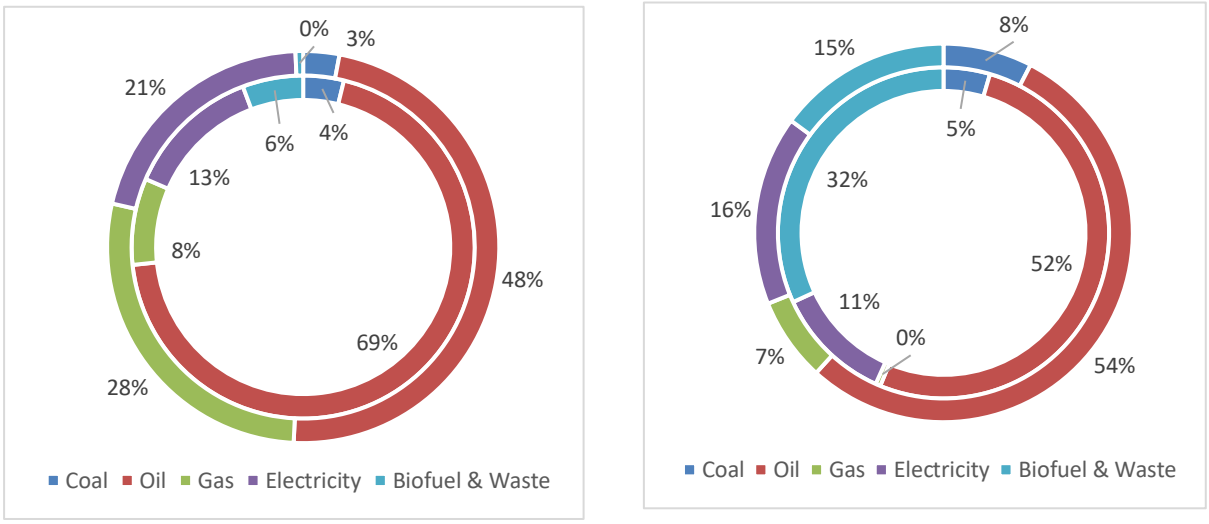


(a) (b)

Figure 4. Vietnam's energy mix (a) and Myanmar's energy mix (b) (International Energy Agency, 2019).

Unlike Vietnam, whose energy mix is already dominated by fossil energy, Myanmar's energy consumption still depends on biofuels as shown in Figure 4(b). In Myanmar, the use of biofuel energy has an impact on carbon intensity, the impact of which is not yet dominant. During 2000 to 2010, carbon intensity had a positive impact on reducing CO_2 emissions. However, between 2010 and 2017, Myanmar's fossil energy grew rapidly, which had an impact on carbon intensity and led to an increase in Myanmar's CO_2 emissions. Myanmar's power generation in 2012 was still dominated by hydropower, which accounts for 74% of total power generation, but Dobermann (2016) estimated that the

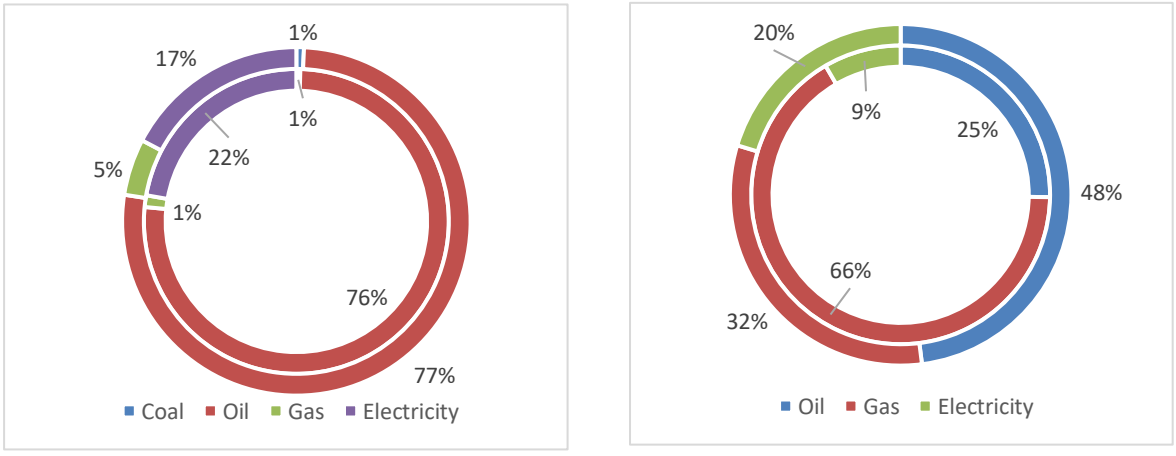
contribution of hydropower in 2030 will be only 38%, and the role of hydroelectric power will be used by coal and other sources of fossil energy.



(a) (b)

Figure 5. Malaysia's energy mix (a) and Thailand's energy mix (b) (International Energy Agency, 2019).

The upper-middle and high income countries of ASEAN, namely Malaysia, Thailand, Brunei Darussalam, and Singapore, show the positive impact of carbon intensity. Figure 5(a) and 5(b) show the energy mix of Malaysia and Thailand, respectively. The energy used by the two countries is the same as lower-middle income countries, but the difference is that both countries' energy consumption is dominated by oil, and the carbon intensity of oil is lower than coal. Even natural gas–the energy source that produces the least CO_2–is growing rapidly in Malaysia, accounting for only 8% of energy consumption in 1990 and rising to 28% in 2017. The new effect of carbon intensity impacts the third phase of CO_2 emission reduction, which is due to the doubling of gas consumption throughout 2010-2017 and the slowdown in coal growth (International Energy Agency, 2019). The results obtained in Thailand and Malaysia reinforce the results of Yao et al. (2015) believe that to ensure emission reductions during economic expansion, the intensity effect should also focus on changing the energy mix to renewable energy to reduce its carbon content.



(a) (b)

Figure 6. Singapore's energy mix (a) and Brunei Darussalam's energy mix (b) (International Energy Agency, 2019).

Singapore's carbon intensity is indirectly affected by the country's economic structure. Service industry is Singapore's leading industry, and this industry produces almost no CO_2 emissions. According to the IEA (2019), Singapore's commercial and public services sector contributed only 1 $MtCO_2$ of carbon

emissions from 1990 to 1994. In addition, Singapore's energy structure is dominated by oil and electricity, as shown in Figure 6(a). Coal is only used in the industrial sector, and its share is much smaller than that of oil in the industrial sector. Ninety five percent of Singapore's electricity comes from natural gas (Energy Market Authority, 2018). The Singapore government's policies on energy industry development and research and development investment encourage natural gas use and energy diversification, including renewable energy (Ministry of Trade and Industry, 2007).

Brunei Darussalam's economy is focused on the industrial sector, especially oil and gas extraction, which accounted for 45.7% of Brunei Darussalam's GDP in 2018 (Ministry of Finance and Economy, 2019). Although still focused on the industrial sector, Brunei Darussalam's energy use is dominated by oil and natural gas. This is different from developing countries in ASEAN which still use coal as an energy source in the industrialization process. The use of oil and gas also affects the carbon intensity of the energy mix in Brunei Darussalam.

4. Conclusions

The results show that if the population impact causes an increase in CO_2 emissions in all ASEAN and ASEAN countries, the contribution that occurs in each period decreases. This is due to the decline in the ASEAN population growth rate. Migration is mostly done by residents of developing countries to get a more prosperous life, but the population level is still high in ASEAN. Therefore, the population effect still has a negative effect on CO_2 emissions, but it is not as significant as the effect of economic activity. The impact of economic activities has increased CO_2 emissions from all ASEAN countries except Brunei Darussalam. This impact is also a determinant of CO_2 emissions in Indonesia, Malaysia, Singapore, Thailand, Philippines, Vietnam, and Myanmar. The different results given by countries are due to the different economic structures of each country. Countries whose economic structure focuses on the industrial sector tend to make carbon emissions in that country increase significantly. In contrast, countries concentrated in the service sector, such as Singapore, whose economic activities still have a negative impact on CO_2 emissions but experience a decrease in each period.

The energy intensity effect has a positive impact on CO_2 emissions in Indonesia, Philippines, Vietnam and Myanmar. Energy intensity has increased CO_2 emissions in Malaysia, Thailand, Singapore and Brunei Darussalam. The different results are due to the fact that Indonesia, Philippines, Vietnam and Myanmar have higher energy efficiency than Malaysia, Thailand, Singapore and Brunei Darussalam. The carbon intensity effect has led to increased in CO_2 emissions in Indonesia, Philippines, Vietnam, Myanmar and ASEAN. Meanwhile, Malaysia, Thailand, Singapore, and Brunei Darussalam have the opposite effect, which CO_2 emissions have decreased due to carbon intensity. The energy mix of various countries affects the impact of national carbon intensity. Each country's energy mix affects the effect of the country's carbon intensity, where the energy mix in Indonesia, Philippines, Vietnam and Myanmar is still dominated by fossil energy and its growth, especially coal is relatively fast. On the other hand, Malaysia, Thailand, Singapore, and Brunei Darussalam energy mix is dominated by less carbon-intensive energy sources such as gas and oil.

In terms of policy implications, the results of this article show that the ASEAN economy, as a fast-growing economy, is highly dependent on energy consumption. Thus, the increase in carbon emissions is driven by aggressive economic output and increased energy consumption. Therefore, policymakers should consider energy resource integration strategies to achieve tremendous improvement in environmental quality without affecting economic growth. According to the analysis, the use of renewable energy is conducive to improving the quality of the environment, since renewable energy produces much less pollution than the use of fossil energy. The use of renewable energy should be concentrated in the industrial sector, which generates the highest carbon emissions. Finally, effectively reduce carbon intensity and emission factors, like implement a carbon market. This implementation can be achieved by developing a carbon trading system and implementing a carbon pricing.

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