Multi-Analysis Environmental Kuznets Curve for Developing Country in Southeast Asia: Using Macro Economics Perspective

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***Abstract*—This study aims to determine the relationship between Greenhouse Gas Emissions (GHG), land area, population, Electric Power Derived from Fossil Fuel, and economic activity and identify whether the Environmental Kuznets Curve (EKC) is applicable to developing countries in Association of Southeast Asian Nations (ASEAN). The data used is panel data of ten developing countries in ASEAN from 1999-2020. The analysis used is regression panel data to determine what variables affect GHG, which is explained using spatial tools GeoMap Orange Data Mining. Empirical results show that the EKC hypothesis is not proven in developing countries in ASEAN. In addition, area, population, electric power derived from fossil fuels, and economic growth significantly affect GHG. This indicates the need for strict regulation to reduce GHG gas emissions contributing to climate change. Furthermore, it is essential to promote public support for the adoption of energy-efficient practices, enhance the utilization of renewable energy sources, shift energy consumption patterns, transform exported goods to low-carbon alternatives, and assess the enforcement of global agreements influencing sustainable development strategies within every developing country in the ASEAN.**

***Keywords*—environmental kuznets curve, gross domestic product, greenhouse gas emissions, GeoMap orange data mining, foreign direct investment, developing countries, ASEAN**

I. Introduction

Regulations to address climate change were established in Paris Agreement in 2015 as a replacement for the previous Kyoto Protocol of 1997 [1]. Countries that are members of the United Nations Framework on Climate Change Conference (UNFCCC) adopted this agreement as a coordinated effort to address climate change on an international scale [2–4]. Unlike the 1997 Kyoto Protocol, Paris Agreement does not set specific emissions reduction targets. Still, it aims to set overall climate change goals and allows countries to determine how and to what extent they can contribute to achieving those goals [5–7]. Further implementation of the Paris Agreement was carried out through a climate change conference by the United Nations from October 31 to November 12, 2021, in Glasgow, Scotland. The event was a reminder that it is necessary to carry out a big agenda to discuss alleviating climate change due to human activities [8].

According to the European Union Officials, several factors are causing global climate change, the biggest being greenhouse gas emissions (GHG) [9]. The increase in greenhouse gas emissions is an environmental degradation and an urgency faced by countries in the world. Previous research posited that the causes of the increase in greenhouse gas emissions include macroeconomic factors and economic activity [10–13]. One of the macroeconomic factors causing the increase in GHG is the growth economy calculated through Gross Domestic Product (GDP). The Environmental Kuznets Curve (EKC) hypothesis explains the inverse U-shaped relationship between economic growth and environmental degradation [14]. This indicates that environmental degradation is increasing in the early stages of economic growth due to increased pollutant release and extensive resource exploitation [15]. These resources are used as industrial raw materials to run a country's economy. However, GHG will increase due to the side effects of industrial activity and some of these problems occur in developing countries. For example, Mahira's research [16] showed that Indonesia, Thailand, Vietnam, and Malaysia experienced an increase in GDP accompanied by an increase in GHG from 1990–2019. Not only that, another study conducted by Elder and Ellis [17] states that developing countries, especially the members of the Association of Southeast Asian Nations (ASEAN), also face the same problem. Almost all developing countries in ASEAN still depend on the industrial sector to support their economies.

Developing countries still seek economic growth through the industrial sector and international trade [18]. The increase in the industrial sector and international trade has a positive impact on GDP but also has a negative impact, namely the increase in the greenhouse effect seen from the amount of greenhouse gases that increase yearly [18]. Ten of the eleven member countries of ASEAN, consisting of Malaysia, the Philippines, Indonesia, Thailand, Brunei Darussalam, Cambodia, Myanmar, Laos, Vietnam, and Timor Leste, are still developing countries (Fig. 1) [19, 20]. Singapore is not categorized as a developing country but as a developed country since it has a GDP of USD 72,794 per year in 2021.

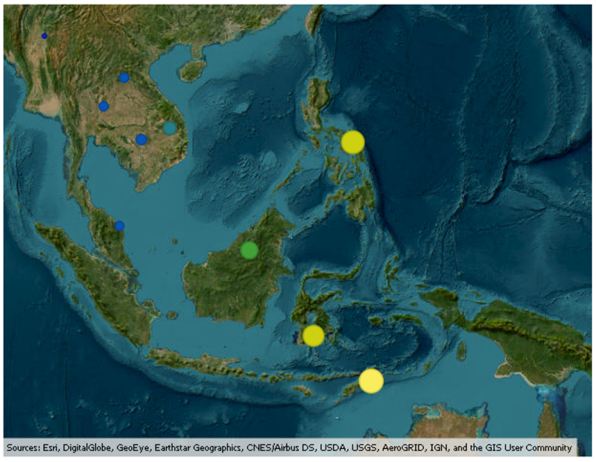


Fig. 1. Map of ten developing countries in ASEAN.

GHG emissions in ASEAN are high, with ten developing countries. According to research by Tritto *et al.* [21], in 2016, ten developing countries in ASEAN contributed 7.35% of the total GHG emissions produced by all countries in the ASEAN world. The level of GHG emissions in ASEAN is expected to continue to increase because countries in ASEAN are currently experiencing an industrialization process that requires a lot of energy, especially energy from fossil fuel, to produce electricity to support the industrial production process [22, 23]. Energy from fossil fuels has a significant role in contributing to GHG emissions, with the energy sector producing around 32,553.48 Kilotons or about 73% of total GHG emissions. At the ASEAN level, fossil energy is the second largest contributor after the forestry and land use change sector. Still, in 2016, the energy sector became the most significant contributor to GHG emissions in ASEAN with a contribution of 49% or around 1,325.01 Kilotons, only slightly different from the forestry and land use change sectors [24, 25]. GHG emissions in these countries are caused mainly by several macroeconomic factors, including GDP, area, population, foreign direct investment (FDI), and dependence on electrical energy sourced from fossil raw materials, as in Fig. 2 [26, 27].

The increase in greenhouse gas emissions in developing countries in ASEAN indicates a decline in environmental performance, contrary to the ten countries' financial performance. Economic performance is represented by the value of GDP per capita, which tends to increase from 1999 to 2020. This means that developing countries in ASEAN have succeeded in implementing development with a sustainable economic structure change strategy. The relationship between environmental quality, which is represented by the number of greenhouse gas emissions in this study, and GDP is depicted on the Environmental Kuznets Curve (EKC).

Sustainable economic development will be achieved in line with sustainable environmental conservation efforts [28]. Researchers in the field of economics have conducted studies on the relationship between economic growth and ecological indicators using the Environmental Kuznets Curve. This theory states that environmental damage will increase with economic development. Still, at a certain point in achieving economic growth, the level of environmental damage will begin to decrease along with the increase marked by an inverted U-curve [11]. The theory of the Environmental Kuznets Curve elucidates the correlation between economic advancement and environmental deterioration within a nation. As per this theory, during the initial stages of low-income levels, the primary emphasis is on augmenting financial gains while disregarding environmental standards. Consequently, pollution levels surge, but as economic development progresses, pollution levels decline. This theory advocates for societal oversight and governmental policies to enhance environmental standards and societal well-being [29].

Several factors can affect the macroeconomy, namely activities in the capital market and also company performance [30]. One such factor is Foreign Direct Investment (FDI), which can increase industrial efficiency and productivity. In addition, FDI can also play a role in increasing exports and creating opportunities. FDI can indirectly increase GHG emissions, but Shahbaz *et al.*'s [31] research on FDI does not have a statistically significant impact in the long run. The increase in greenhouse gas emissions is also attributed to socio-demographic factors, such as population and land area. As the population grows and the land area expands, there is a greater need for human activities, which in turn leads to an increase in GHG emissions. [25, 32, 33].

This study aims to prove the hypothesis of an inverted U-shaped Environmental Kuznets Curve (EKC) to examine the effect of the relationship between the amount of greenhouse gas emissions of developing countries in ASEAN in 1999–2020. In addition, it analyzes the influence of GDP, population, area, foreign direct investment (FDI), and the amount of electrical energy derived from fossils, which are thought to cause an increase in greenhouse gas emissions in developing countries in ASEAN.

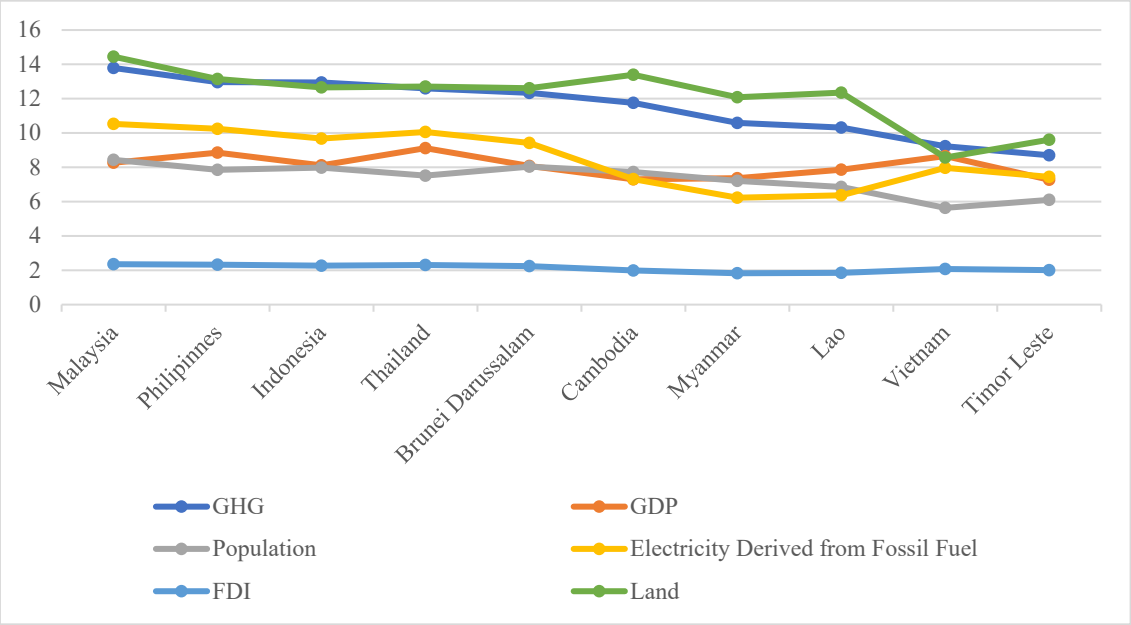


Fig. 2. Greenhouse Gas Emission Levels and Influencing Macroeconomic Factors in ASEAN Developing Countries in 2020.

II. Literature Review

Greenhouse gases (GHG) are gases in the atmosphere that cause the greenhouse effect. Although these gases are naturally present in the environment, human activities can

also cause an increase in greenhouse gases, primarily by burning fossil fuels [34]. Some examples of greenhouse gases found in the atmosphere include carbon dioxide (CO_2), nitrogen dioxide (N_2O), methane (CH_4), and freon. Greenhouse gas emissions naturally result from human daily activities. However, since the 1950s, CO_2 gas emissions have increased significantly due to industrial advances in line with energy consumption [35]. The greenhouse effect can have significant consequences for the environment and human life. Some of the consequences of the greenhouse effect include rising global temperatures, rising sea levels, ecosystem disruption, social and political impacts of climate change, migration crises, and their effects on human health [36].

The Environmental Kuznets Curve hypothesis suggests that many ASEAN countries are classified as developing countries in the early phases of development. As a result, reducing environmental damage is proving difficult as some of these countries still prioritize economic progress and strive to raise environmental awareness. However, there is a paradox when developing countries will experience more severe impacts due to climate change. Regarding GHG emissions, the reason for polluting to meet economic needs is almost unjustified. Economic and carbon dioxide emissions in developing countries in ASEAN tend to increase in the early stages of the EKC hypothesis. Li *et al*. [37] also showed a correlation between GHG emission data and gross domestic product in the ASEAN region. However, previous literature investigating the existence of EKC using GHG emissions as an environmental indicator has shown the opposite result. A study of panel data from several countries by Moise (2023) and Alin *et al.* (2019) successfully validated the EKC. Studies in developed countries, such as those conducted by Hasanov *et al.* [38] and Salahuddin *et al.* [39], can also validate the existence of EKC. However, Zhu *et al.* [40] studied several developing countries in 2016, such as Indonesia, Malaysia, Philippines, and Thailand, and they showed that the kuznet environmental curve does not apply. In addition, studies examining the relationship between GHG emissions and GDP per capita have also shown mixed results. The ties can be in the form of interplay between GHG emissions and GDP [12, 13, 40].

III. Materials and Methods

A. Data dan Variable

The variables used in this study are Greenhouse Gas Emissions (GHG), Gross Domestic Product (GDP), Electrical Energy produced from fossil resources, Area, Community Population, and Foreign Direct Investment. The data used in this study is panel data obtained from the International Monetary Fund (IMF). Testing the EKC hypothesis using GDP and GHG variables using data from 1999–2020 in ten developing countries in ASEAN, a total of 220 data observations were made with consideration of data completeness, especially Timor-Leste's independence. Details of these variable units can be seen in Table 1.

The data used in this study was then analyzed using several methods carried out through several stages, as in Fig. 3.

Table 1. Details of research data

Variable	Operational Definition	Unit	Data Sources
Greenhouse Gas Emissions (GHG)	These gases can capture the sun's heat in the Earth's atmosphere and cause the greenhouse effect.	Equivalent to kilotons of CO_2	IMF
Gross Domestic Product (GDP) Per Capita	An economic measure that measures the market value of all goods and services produced within a country divided by its population	US Dollar	World Bank
The electrical energy generated from fossil resources (Fossil)	The amount of electrical energy produced by fossil resources	KwH	IMF
Country Area (Land)	Area of each country	Km^2	IMF
Population (Population)	The number of people in each country.	Million People	IMF
Foreign Direct Investment (FDI)	Ownership of shares in a foreign company or project carried out by investors, companies, or governments from other countries	Juta USD	IMF

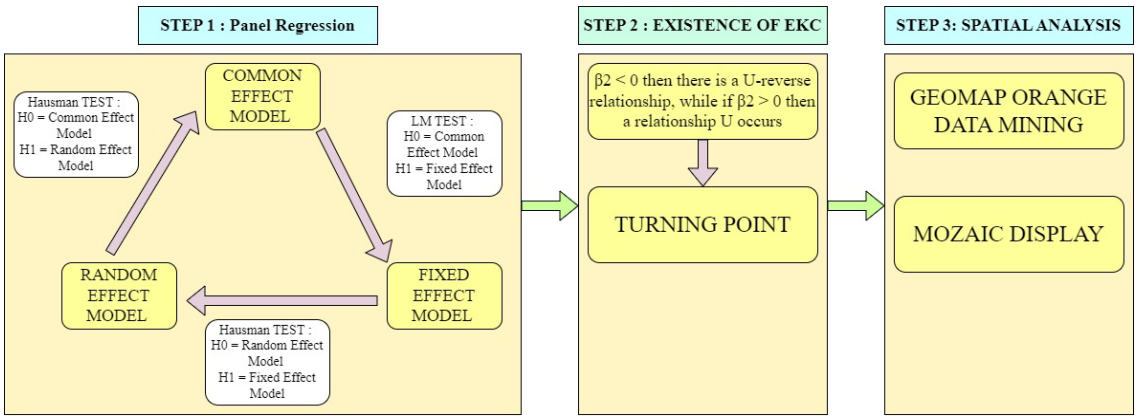


Fig 3. Step of Research.

B. Factors Affecting GHG

This research uses three methods divided into three stages. The first stage is to estimate the relationship between the dependent and independent variables, which aims to analyze the factors causing the existence of EKC in developing countries in ASEAN. In addition, it is used to find the corresponding equation model. The stages use the panel regression method with the following equations:

$$lnGHCO\ 2_{\ it} = \alpha_i + \beta_1 \ln (GDP)_{it} + \beta_2 \ln (GDP)^2_{\ it} + \beta_3 \ln (Fossil)_{it} + \beta_4 \ln (Land)_{it} + \beta_5 \ln (Populasi)_{it} + \beta_6 \ln (FDI)_{it} + e_{it} \quad (1)$$

where:

α: intercept

β: coefficient
e: standard error
lnGHG: Greenhouse Gas Emissions per capita
lnGDP: Gross Domestic Product per capita
lnFossil: The amount of electrical energy produced from fossil resources
lnLand: Country Area
lnPopulasi: Total population
lnFDI: Foreign Direct Investment
i: developing countries in ASEAN
t: period (year 1999 – 2020)

C. Kuznets Environmental Curve Estimation

Eq. (2) estimates the existence of EKC as in the research of Cahyani & Aminata [14] by looking at the coefficients β1 and $\beta 2$, namely: if $\beta 2 < 0$, then there is a U-reverse relationship, while if $\beta 2 > 0$, then a U relationship occurs. The test is then continued by knowing the level of GDP and GHG through Turning Point (TP) with the formula:

$$TP = -\frac{\beta_1}{2\beta_2} \quad (2)$$

D. Spatial Distribution of Influential Independent Variables

The last stage is determining the spatial distribution analyzed using GeoMap Orange Data Mining mapping. It aims to assess the dominance of a country in developing countries in ASEAN on influential independent variables. The results that have been obtained are also analyzed in relation to the relationship through Mosaic Display with processing using the Orange Data Mining application.

IV. Result and Discussion

A. Influencing Factors GHG

Testing of macroeconomic variables on GHG in developing countries in ASEAN was carried out using the panel data regression method, which was carried out through several stages to obtain the best equation model and determine the factors that influenced the increase in GHG in ten developing countries in ASEAN.

1) Chow test

The Chow test is a test that shows the results of the F test value. If the P-Value value < Alpha 0.05, then H_a is accepted so that the best model choice is the Fixed Effect Model (FEM), but if the opposite, then the best model is the Common Effect Model (CEM). The results of the Chow test in this study showed a P-Value value of 0.0000, so the best model choice was FEM.

2) Hausman test

The Hausman test is a test that shows the results of the F test value. If the P-Value value < Alpha 0.05, then H_a is accepted so that the best model choice is the Fixed Effect Model (FEM), but if the opposite, then the best model is the Random Effect Model (REM). The results of the Chow test in this study showed a P-Value value of 0.0000, so the best model choice was FEM.

3) Regression result of T-statistical test

T-statistical testing in this study was measured using regression functions, which include t-statistic, F statistic, and coefficient of determination. The goal is to partially and simultaneously determine the effect of the independent variable on the dependent variable and the proportion of the independent variable in explaining changes in the dependent variable. The test results are shown in Table 2.

Table 2. Panel data regression results

Variable	Coefficient	Probability
C	–5,359	0,000
LNGDP	9.226	0,000
$LNGDP^2$	–0,00014	0,000
LNFOSSIL	0,034	0,000
LNLAND	0,861	0,000
LNPOPULASI	0,314	0,000
FDI	0,019	0,003
R-Square		0,776
Prob > F		0,000

Source: Data Processed (2023)

Based on the results of the regression estimations seen in Table 2, the regression equation can be obtained as follows:

$$lnGHG_{it} = -5{,}359_i + 9{,}226\ln(GDP)_{it} - 0{,}000142\ln(GDP)^2_{it} + 0{,}034\ln(Fossil)_{it} + 0{,}861\ln(Land)_{it} + 0{,}314\ln(Populasi)_{it} + 0{,}019\ln(FDI)_{it} + e_{it} \quad (3)$$

The results of Equation 3 regression show that GDP per capita has a significant positive effect on GHG. This indicates that if GDP per capita increases by 1%, GHG increases by 9.2%, with an increase in GDP per capita (the highest economic growth) occurring. The increase in GDP per capita was caused mainly by increased activity in the industrial sector. Research conducted by Juhro [19] shows that developing countries, most still rely on the manufacturing industry to improve their economic growth. Conversely, the manufacturing industry in developing countries in ASEAN has largely not applied environmentally friendly technology [41]. The following influential variable is electrical energy derived from fossil resources, which shows that a % increase in the percentage of electrical power derived from fossil resources by 1% will increase GHG by 0.03%. This indicates that electrical energy derived from intended fossil resources to increase economic activity also impacts environmental degradation. Indonesia is a developing country with the highest amount of electrical energy derived from fossil resources in ASEAN, with an average subsidy from 1999–2020 of 37459.1 Kwh per year.

Significant results were also seen in the broad influence of regions with GHG emissions. Area is the variable with the highest significant influence on this study. Namely, every 1% of the area of a developing country in ASEAN can have an impact of 0.86% GHG. This aligns with the research of Kurniarahma *et al.* [42] and Prabowo & Budiastuti [43], namely that a large area can increase social and economic activities such as industrial development and urbanization. This activity, of course, will cause side effects in the form of industrial residues, one of which is GHG emissions [44]. According to IMF data on ten developing countries in ASEAN from 1999 to 2020, Indonesia, Myanmar, and Vietnam have the most significant areas and the highest GHG emission levels of the ten developing countries in ASEAN.

The following macroeconomic variable that has a significant positive effect is the population. An increase in the population by 1% led to an increase in GHG by 0.31%. An increase in population will lead to more human resource productivity, which has a side effect on increasing GHG [45]. This is supported by the results of research conducted by

Widyawati *et al.* [46], which states that countries with large populations tend to have high GHG values. The more population a country has, the higher the carbon dioxide emissions produced [47]. This follows the EKC theory because the more significant the population, the more daily activities require energy, thus contributing to high carbon dioxide emissions. Examples of activities contributing to carbon dioxide emissions are infrastructure, transportation, energy, and the transition from agriculture to industry. All these activities increase the use of fossil fuels, ultimately leading to increased environmental pollution or carbon dioxide emissions. Population size also affects a country's carbon dioxide emissions [48]. City dwellers' level of education and awareness of daily behaviour also affects the surrounding environment. More people in an area will increase activities and mobility that require supporting energy such as electricity and fuel oil. Increasing energy demand will cause an increase in residues in the form of carbon monoxide (CO), which is included in greenhouse gas emissions [47].

Foreign Direct Investment (FDI) in developing countries also contributes to the increase in GHG. The regression results stated that every increase in FDI by 1% would increase GHG by 0.02%. This indicates that foreign investment is one of the supporting factors for industry and economies in developing countries in ASEAN. The results of this estimate are also reinforced by findings in the research of Prinadi *et al.* [49], which said that GHG levels in Indonesia, Malaysia, Brunei Darussalam, the Philippines, and Vietnam increased, one of which was due to an increase in FDI.

B. Kusnetz Environmental Curve Estimation

This study estimates the Environmental Kuznets Curve between environmental degradation depicted by the average amount of GHG and the average GDP per year in developing ASEAN countries for 1999–2020, shown in Fig. 4.

The estimation results in Fig. 4 show that the inverse U-shaped EKC theory hypothesis is not proven. This is evidenced by the significant positive relationship between GDP and GHG, which means that if the amount of GDP per capita increases, the amount of greenhouse gas emissions, an indicator of environmental degradation, also increases. The regression panel data in Eq. (3) also supports the data processing results in Fig. 4. The equation is then tested more deeply using regression to find a Turning Point with a GDP value squared as follows:

$$TP = -\frac{9{,}226491}{2(-0{,}000142)} \quad (4)$$
$$= -\left(\frac{9{,}226491}{(-0{,}000284)}\right)$$
$$=32{,}4\%$$

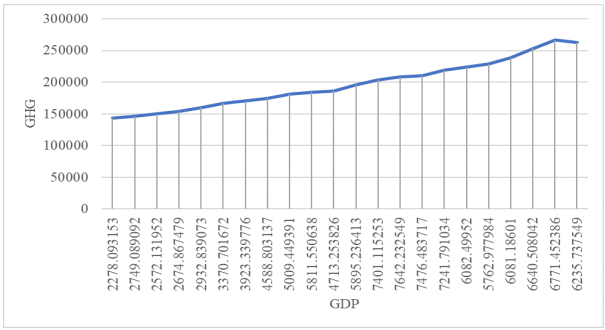


Fig. 4. EKC Developing Countries in ASEAN Years 1999 – 2020.

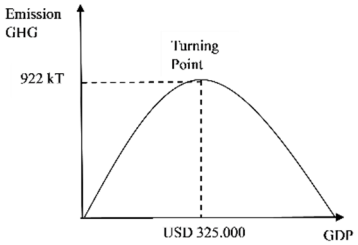


Fig. 5. Turning Point to EKC.

Table 4. GDP of Developing Countries in ASEAN 1999-2020 (USD Percentage)

Year	Country										Average
	Malaysia	Philipinnes	Indonesia	Thailand	Brunei Darussalam	Cambodia	Myanmar	Laos	Vietnam	Timor Leste	
1999	8.17	7.02	6.50	7.62	9.55	5.69	4.83	5.6	5.91	5.71	6.66
2000	8.32	6.98	6.65	7.60	9.80	5.71	5.01	5.8	5.98	6.04	6.78
2001	8.28	6.90	6.61	7.54	9.71	5.78	4.91	5.8	6.01	6.28	6.78
2002	8.34	6.94	6.79	7.65	9.73	5.83	4.88	5.7	6.07	6.25	6.82
2003	8.40	6.96	6.96	7.76	9.83	5.90	5.11	5.9	6.19	6.27	6.92
2004	8.50	7.02	7.04	7.88	9.99	6.02	5.29	6.0	6.31	6.14	7.02
2005	8.62	7.13	7.13	7.96	10.17	6.16	5.40	6.2	6.54	6.17	7.14
2006	8.72	7.28	7.36	8.11	10.33	6.29	5.51	6.4	6.67	6.12	7.28
2007	8.87	7.46	7.52	8.28	10.38	6.45	5.77	6.6	6.82	6.28	7.44
2008	9.03	7.60	7.67	8.37	10.53	6.61	6.16	6.8	7.05	6.43	7.62
2009	8.88	7.55	7.71	8.33	10.22	6.60	6.40	6.8	7.11	6.53	7.62
2010	9.09	7.70	8.04	8.52	10.45	6.66	6.64	7.0	7.43	6.70	7.83
2011	9.23	7.80	8.19	8.59	10.74	6.78	6.99	7.2	7.58	6.84	8.00
2012	9.27	7.89	8.21	8.66	10.75	6.86	7.06	7.4	7.69	6.93	8.07
2013	9.28	7.95	8.19	8.71	10.69	6.92	7.09	7.5	7.77	7.09	8.12
2014	9.31	7.98	8.15	8.67	10.62	7.00	7.12	7.6	7.85	7.11	8.14
2015	9.18	8.00	8.11	8.65	10.33	7.07	7.11	7.7	7.86	7.19	8.12
2016	9.16	8.02	8.18	8.67	10.19	7.16	7.06	7.7	7.92	7.21	8.13
2017	9.21	8.03	8.25	8.77	10.25	7.24	7.07	7.8	8.00	7.16	8.18
2018	9.31	8.07	8.27	8.87	10.35	7.34	7.15	7.9	8.09	7.12	8.24
2019	9.32	8.14	8.33	8.94	10.33	7.42	7.17	7.9	8.16	7.37	8.30
2020	9.23	8.08	8.27	8.85	10.21	7.36	7.30	7.9	8.18	7.41	8.28

The estimation results on the equation show that the inverse U-shaped EKC theory hypothesis has not been proven. The Turning Point value in Eq. (4) shows a result of 32.4%, so at the beginning of economic growth, the ten developing countries in ASEAN will increase GHG emissions. However, after reaching the GDP value of 32.5%, economic growth will improve environmental quality with various policies. This is because most of these countries are still in the pre-industrial

and industrial economies stage, where economic growth and GHG emissions have increased together. The calculation results are also supported by GDP data, as in Table 3, which indicates that the average GDP is still below 32.5% and has not reached the turning point. The Turning Point at the EKC in developing countries in ASEAN will be achieved after reaching and exceeding the 32.5% GDP value shown in Fig. 5.

The positive relationship between GDP and GHG is significant, which means that if the GDP per capita increases, the greenhouse gas emissions that are indicators of environmental degradation also increase. This shows that developing countries in ASEAN have only experienced two stages of the EKC hypothesis, namely:

1) Pre-industrial economies stage

This step occurred from 1999 to 2016, which showed massive industrial development. An increase in GDP per capita is followed by an increase in GHG, indicating a decline in environmental quality [14]. This can be suspected by the change in economic structure from agriculture to industry [29].

2) Step of industrial economies

This step occurred from 2017 to 2020, marked by the industry-dominated economic structure. Environmental conditions initially neglected began to be considered again with various programs supporting environmental care. Furthermore, the COVID-19 pandemic has not only resulted in various consequences, but it has also played a significant role in the reduction of GHG levels in developing nations within the ASEAN region. This decline reached its highest point in 2019.

Both stages are also supported by data that states that the high level of GHG in developing countries in ASEAN is due to the majority of these countries still using non-renewable energy that is less environmentally friendly. One of the non-renewable energy sources comes from fuel oil and coal, which are the cause of high amounts of pollutants that increase the greenhouse effect [50]. Indonesia is a developing country in ASEAN with the average use of non-renewable fuels derived from fossil fuels to meet the most significant electricity needs of 16,300 Megawatts/hour, followed by Thailand and Malaysia. The following is the average use of non-renewable energy sources derived from fossil fuels from developing countries in ASEAN in 2000 – 2020:

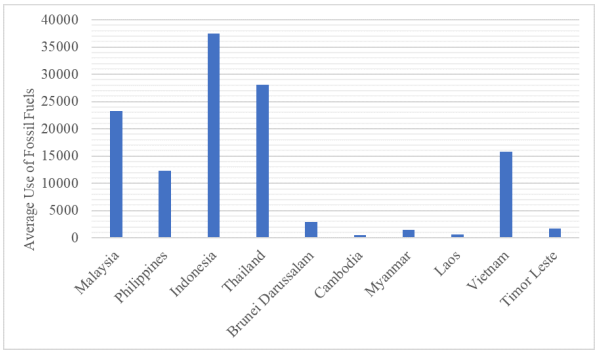


Fig. 6. Average Use of Fossil Fuels in Each Developing Country in ASEAN 1999–2020.

The use of fossil fuels as a source of energy-producing high electricity is positively correlated with the population and area of a country. The increasing population resulted in a soaring need for electrical energy [51]. Not only that, but the region also supports the increase in the need for electrical energy to facilitate equitable regional development. Indonesia, Thailand, and Malaysia use electrical energy derived from fossil resources [52]. The industrial sector is still the dominant sector, and it is indicated to be one of the supporters of increasing the need for electrical energy. Some previous studies have said that developing countries in ASEAN have implemented policies limiting the use of non-renewable energy and optimizing renewable energy as raw materials for power plants. However, these efforts are still in the development stage, so they are not optimal for implementation [52–54].

The invalidation of the Kusnetz Environmental Curve in developing countries in ASEAN shows the need for governments in their respective countries to be aware of economic improvements that are not accompanied by increased environmental awareness. For this reason, the government needs to be more proactive in making environmentally friendly economic policies such as increasing the share of renewable energy in the energy mix, energy conservation, public transportation efficiency, and the adoption of electric vehicles. Previous studies that could not validate the existence of EKC, such as Alin *et al.* [29] and Cahyani and Aminata [14], provided similar recommendations related to energy and transportation policies. However, the findings that show the positive influence of GDP per capita on GHG in this study imply the need for government prudence in implementing GHG reduction policies to avoid slowing economic growth.

Government policies that use more fossil fuels in electricity and transportation than renewable energy are based on economic reasons [55]. Without considering the negative external impacts of using fossil fuels, the financial cost is lower than that of using renewable energy [56]. Therefore, if the government imposes an increase in the use of renewable energy, the cost of carrying out economic activities in the country will increase, so economic development risks being hampered [57].

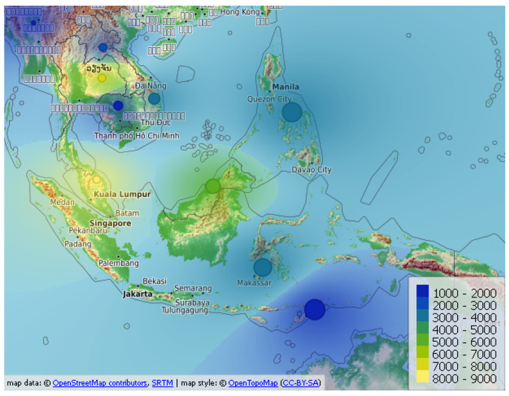
C. Spatial Analysis

1) Area Mapping Based on Factors Affecting GHG

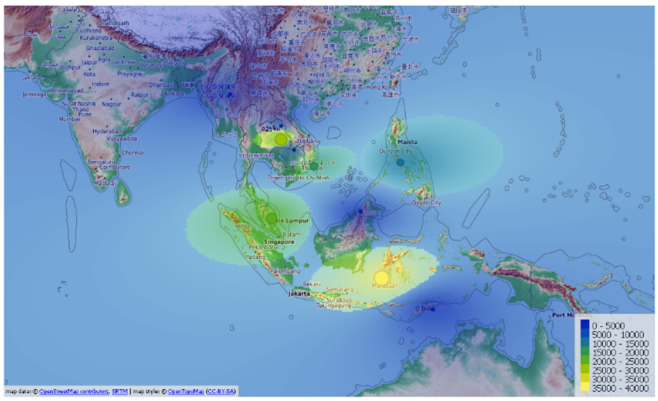
The results of multiple panel estimation in this study show that macroeconomic factors influence the increase in GHG. Namely: GDP, Electrical Energy produced from fossil resources, Area, Population, and FDI. The results are then analyzed using mapping and graphs to determine the data distribution in each country. The distribution mapping was done using Geo-Map diagnosed with Orange Data Mining in Figs. 4 and 5. Fig. 4(a) shows Malaysia has the highest average GDP per capita, USD 9109.15 million. Malaysia's high average GDP per capita is fueled by increased global demand for electronics and better trade terms for commodities such as oil and gas. Not only that, the domestic sector also supports substantial job opportunities that have increased private consumption, while investment also plays a role in driving growth [58]. The 4D Figure illustrates that Vietnam leads in terms of Foreign Direct Investment (FDI) with approximately USD 11 million. This can be attributed to the significant capital infusion, the level of trust, and the overall health of the industry. Strong global demand for electronic goods and better trade terms for commodities such as oil and gas are significant factors in high levels of investment. In addition, increasing employment opportunities

in the country also contributes to increasing private consumption, while investment also plays a role in encouraging economic growth [59, 60].

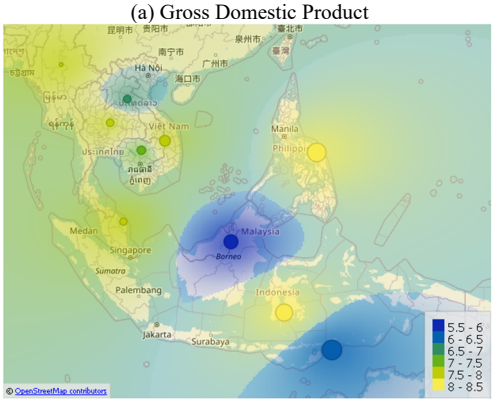
Figs. 7(b, c) and 8 illustrate Indonesia as a country that relies on fossil resources for its electricity generation, has a large population, and exhibits high levels of greenhouse gas emissions. Specifically, Indonesia produces 3748 kWh of Electrical Energy, has a population of 268 million people, and emits 973136,1357 Kilo Tons of GHG. This is because Indonesia is still experiencing an increased population and dependence on fossil fuels. In addition, effective policies for GHG pollution control have not been implemented [61, 62].



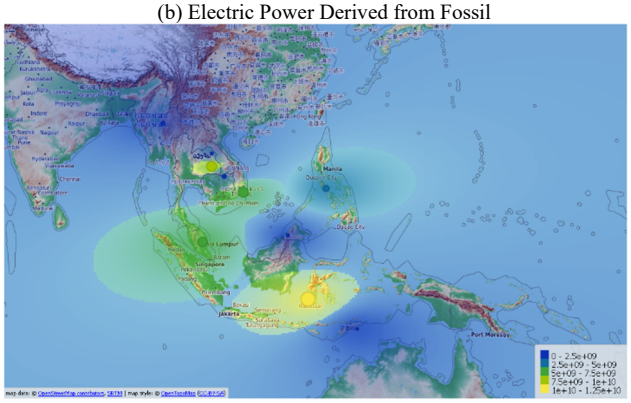
(a) Gross Domestic Product



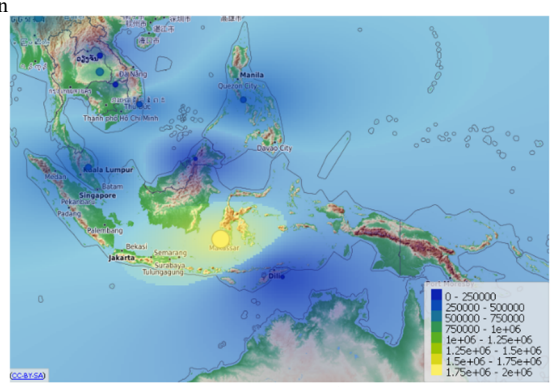
(b) Electric Power Derived from Fossil



(c) Population



(d) FDI



(e) Land

Fig. 7 GeoMap analysis of macroeconomic factors.

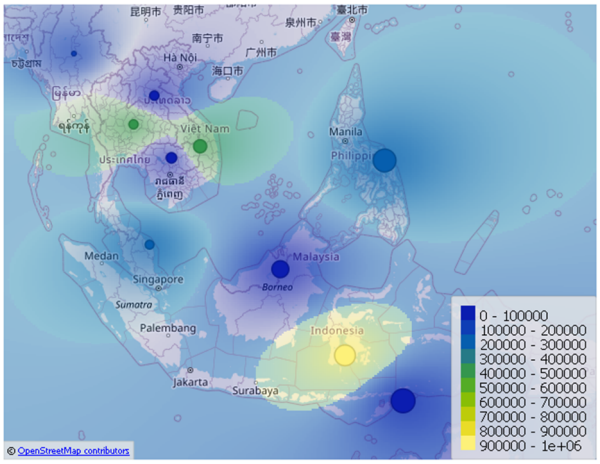
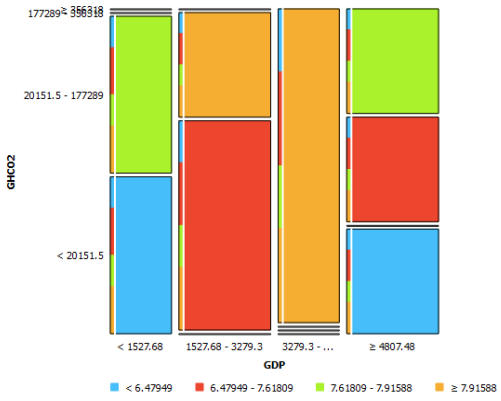


Fig. 8. Distribution of GHG Data in Developing Countries in ASEAN.

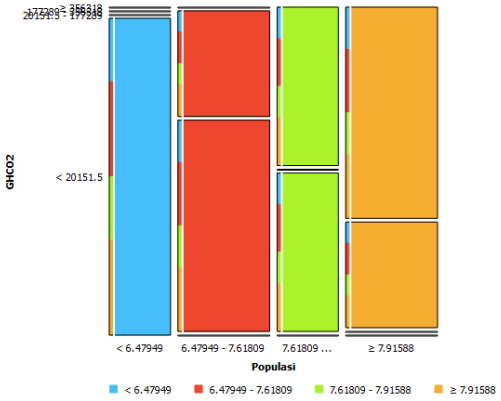
Fig. 9 depicts the correlation between significant factors, such as GDP, fossil fuel-based electricity generation, area, population, and FDI. It reveals that as the number of independent variables increases, there is a corresponding rise in greenhouse gas emissions.

Fig. 9 showcases a mosaic display pattern that has been processed through the Orange Data Mining application. This particular pattern reveals a correlation between the GDP and the production of electrical energy from fossil resources. It suggests that as the GDP increases, so does the amount of electrical energy generated from fossil resources. Additionally, the pattern indicates that there is a positive relationship between the area, population, FDI, and the value of GHG. In other words, as these factors increase, the value

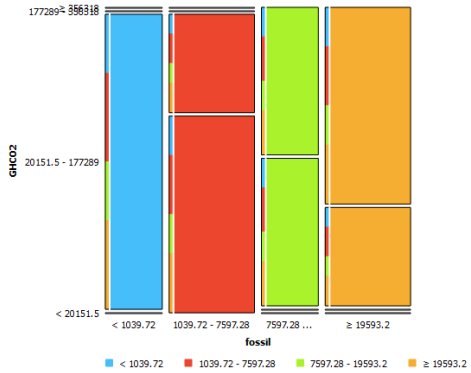
of GHG also tends to increase [63]. Therefore, it is necessary to formulate policies related to investment that aim to reduce the increase in carbon emissions by prioritizing investment in sectors that support environmental sustainability.



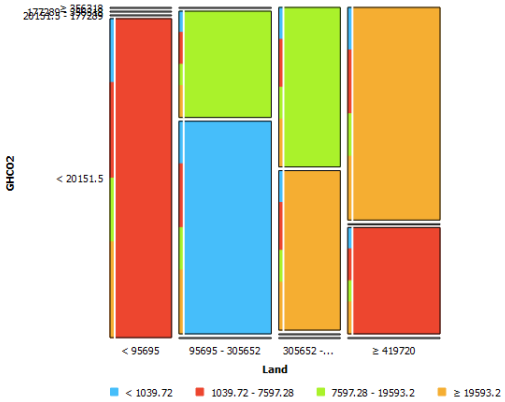
The relationship between GDP and GHG.



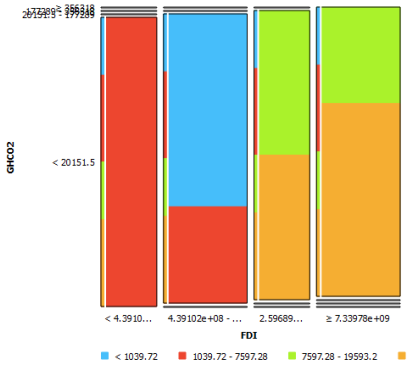
Population's Relationship with GHG.



The relationship of electrical energy generated from fossil resources with GHG.



Land's relationship with GHG.



FDI's relationship with GHG

Fig. 9. The relationship between variables that affect GHG with GHG.

V. Conclusion

The hypothesis of the existence of EKC in developing countries in ASEAN from 1999 to 2020 has not been proven. This is because these countries have economic growth in the form of high GDP and are accompanied by increased environmental degradation. In addition, the majority of developing countries in these countries still rely on industries based on non-renewable resources. This fact is supported by the results of regression analysis of panel data on the factors causing the increase in GHG in developing countries in ASEAN 1999 – 2020. The regression results stated that the variables GDP, Electrical Energy produced from fossil resources, Area, Population, and FDI significantly positively affected GHG. This shows that despite the increase in economic standards during this period, public environmental awareness in each country has not experienced a significant increase.

The government needs to take proactive steps by formulating environmentally sound economic policies and increasing public awareness of the importance of protecting the environment. Several strategies can be used to implement the green economy. One of them is the development of the green revolution, which aims to increase the efficiency of using natural resources and reduce negative environmental impacts. Another strategy is using green chemistry, which aims to prevent harmful chemicals and increase the efficiency of atomic use. Safer chemical synthesis is also one of the essential strategies for implementing the green economy. In addition, the need for industrial prevention policies must also be considered to reduce negative impacts on the environment.

To achieve success in implementing the green economy, active stakeholder participation must be involved. By involving the community in providing ideas or ideas that can be applied, implementing the green economy can be more effective and efficient. In addition, industrial product companies also have an essential role in implementing the green economy. They must make policies that integrate green economy principles through corporate social responsibility programs. One step that can be done is to apply pollution filtration technology before the emissions are discharged into the air. Thus, companies can contribute to maintaining environmental sustainability and reducing negative environmental impacts.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

AR wrote and analyzed data, IM revised and reviewed citations, and EG reviewed layouts and revised papers. All authors have checked the entire paper

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