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Untangling the Web: Exploring the Effect of GDP and Corruption on CO2 Emissions - A Comparative Analysis Across Nations and Within ASEAN

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Abstract

Environmental pollution and climate change have severely threatened human health and ecosystems. This study examines the effect of GDP and corruption on CO2 across countries, with a specific focus on ASEAN members. Using panel data from six ASEAN countries. The methodological approach includes Fixed Effects and Random Effects regression techniques, with model selection based on the Chow and Hausman tests using Eviews tool. The findings reveal that GDP has a significant and positive impact on CO2, indicating that economic growth is associated with increased carbon emissions. Conversely, corruption does not exhibit a statistically significant effect on CO2 emissions, suggesting that governance quality alone may not directly drive environmental degradation. Furthermore, when analyzing ASEAN countries with monarchical governments Malaysia, Thailand, and Cambodia the results remain consistent, reinforcing the relationship between GDP and emissions while showing no direct impact of corruption on environmental outcomes. Governments should enforce policies that mitigate carbon emissions while maintaining economic expansion. Additionally, stronger institutional frameworks and anti-corruption measures must be implemented alongside climate policies to achieve long-term sustainability goals. The findings contribute to the broader discourse on economic development and environmental governance in ASEAN countries and provide a foundation for future research on policy interventions aimed at reducing CO2.

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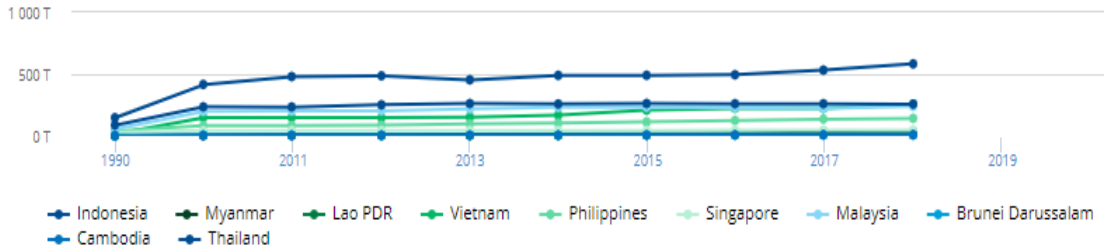
INTRODUCTION

The Climate change has caused many countries to be faced with improving the quality of ecosystems. Environmental pollution and climate change have severely threatened human health and ecosystems. The mass production of pollutants released into the air has had severe impacts on human health and the environment. In the modern era, industrialisation and urbanisation have advanced rapidly, reaching alarming levels worldwide. One of the greatest threats to public health is air pollution caused by human activities, contributing to nearly 9 million deaths annually (Edo et al., 2024). Pro-environmental policies are urgently needed to be developed and enacted for the safety of all.

However, the country is also faced with the problem of maintaining economic stability and seeking economic growth amid dynamic conditions. Higher economic growth and energy consumption have undoubtedly led to more significant CO2 emissions and environmental damage. Environmental damage is predicted to occur alongside high economic growth. This can be understood as the increase in energy consumption is always accompanied by a rise in CO2 emissions. Most fuel sources come from non-renewable fossil fuels, yet their usage is becoming increasingly widespread. The rapid economic growth in Southeast Asia over the past few decades has led to a high energy dependency, which in turn has resulted in increased consumption and a continuous rise in emissions (Chontanawat, 2020). Member States of the Association of Southeast Asian Nations (ASEAN) have contributed many carbon emissions during industrialization (Salman et al., 2019).



Source: World Bank (2021) World Development Indicator

Figure 1. CO2 Emissions in Southeast Asia

Based on data on CO2 emissions from the world bank, it shows that some ASEAN member countries tend to increase, such as Indonesia, which has experienced a significant increase, while others are relatively constant. Ben Jebli & Kahia (2020) revealed that although various countries have implemented new technologies to minimize lower emission levels and implement various pro-environment policies, the potential for CO2 emissions continues to grow positively. In line with this Nosheen, at al. (2021) stated that an increase in the earth's temperature, which is getting hotter, will be very worrying for humans.

The Environmental Kuznets Curve (EKC) has been used in studies focusing on economic growth and its impact on environmental damage. The EKC curve suggests that CO2 emissions will continue to increase until average income reaches a turning point. At that point, the quality of the environment will begin to improve. Generally, the EKC is perceived to show that the relationship between environmental quality and economic growth/development forms an inverse U-shape. At first, a country will experience environmental pressures along with efforts to increase economic growth until, at a certain point, it will decline again as awareness grows for environmental conservation.

Research on the impact of economic growth on environmental degradation has been widely conducted. CO2 emissions are one of the most noticeable forms of environmental damage

in society because they are closely related to daily life. A study by Raihan and Tuspekova, (2022) found that economic growth will significantly increase carbon emissions. Therefore, this study uses economic growth as a factor. Furthermore, GDP per capita also has an impact on emissions. A higher GDP per capita is predicted to affect increased energy consumption, which ultimately leads to higher emissions. Shahbaz (2021) found that CO2 emissions are influenced by a higher GDP per capita. Another unusual factor is corruption. Although corruption is a legal issue, it is also predicted to affect emissions. Corruption has been found to contribute to the increase in CO2 emissions (Dincer & Fredriksson, 2018). This can be understood as, in maintaining a sustainable balance between the environment and the economy, various countries focus on improving the legal system and controlling corruption, and this has become a priority for many developing countries (Mahmood et al., 2021). Corruption, as a negative practice, has become a frightening issue that contributes to life in developing countries, where entrepreneurs bribe to protect their companies from environmental sanctions (Desai, 1998, in Wang et al., 2019). Sinha et al. (2019) recommends that in the preparation of environmental policies (environment policy) must take into account corruption in order to produce stronger and more effective policy products.

Many studies have been conducted to predict the increase in CO2 emissions in various countries. However, it is still rare to examine how the characteristics of a country differ in addressing the issue of CO2 emissions. The main objective of this study is to provide findings on the increase in CO2 emissions caused by the factors of economic growth, GDP, and corruption, while distinguishing the forms of countries in the Southeast Asia region. So as a differentiator from previous research, this study seeks to divide the discussion into three models, which consist of countries, namely the republic and the kingdom, as well as the ASEAN region.

Environmental Kuznets Curve (EKC)

The Environmental Kuznets Curve (EKC) has become the foundational hypothesis for predicting the relationship between economic growth and environmental quality. According to this curve, CO2 emissions will continue to increase until per capita income reaches a certain point, leading to a change in direction. The relationship between economic growth/development and environmental quality in the Environmental Kuznets Curve is depicted in an inverse U-shape. At first, a country will experience environmental pressures along with efforts to increase economic growth until, at a certain point, it will decline again as awareness grows for environmental conservation.

The Environmental Kuznets Curve (EKC) has been a strong foundation for predicting the relationship between environmental damage and economic growth. The study by Sen & Abedin (2020) uses the EKC as a basis to predict the adverse impacts of energy consumption and environmental quality. Their findings are consistent with the EKC, showing that high energy consumption can worsen environmental quality in the long term in both India and China. Additionally, in the long term, GDP is more likely to reduce environmental quality at a lower rate in China than in India. The static assumptions in the EKC, such as the increase in income, technological advancements, and rising demand, are expected to impact the demand for economic improvements. More simply, environmental degradation at the early stages of economic growth will occur and is considered the best, and perhaps the only, way to achieve a sustainable environment.

Relationship of GDP and CO2 Emissions

Gross Domestic Product per capita is the total value of goods and services produced in a country,

divided by the population at mid-year. This figure is often used to measure the economic growth of a country. However, the economic activities that support this growth generally require energy consumption, which in turn produces waste, such as CO2 emissions, that can harm the environment. In general, countries around the world strive to reduce environmental damage caused by CO2 emissions as a result of economic growth, initially increasing and then decreasing them (Farooq et al., 2021). This forms the basis of the Environmental Kuznets Curve (EKC) hypothesis, which assumes that environmental degradation is caused by economic activity, and as economic conditions improve, the demand for improving environmental quality also increases. The EKC curve initially takes the shape of a bell, followed by an inverted U-shape to illustrate the relationship between economic activity and environmental damage. In the early stages, GDP per capita and CO2 emissions may show a negative trend in the short term, before eventually reaching a turning point. This showed relationship between GDP per capita and CO2 emissions (Demissew & Kotosz, 2019). After this turning point is reached, deliberately designed policies, such as environmental conservation measures, the adoption of more environmentally friendly technologies, and industrial modernisation, can reverse this trend, forming a bell-shaped or inverted U curve. This suggests that the Kuznets Curve hypothesis can be a useful tool for analysing the relationship between economic growth and its impact on the environment.

H1: GDP per capita influences CO2 emissions.

Relationship of Corruption and CO2 Emissions

The phenomenon of exploiting public resources for personal gain has become a persistent issue in government or institutions with no end in sight (Akhbari & Nejati, 2019). Haseeb & Azam (2021) state that the environmental damage caused by corruption can be understood through regulations that do not support environmental protection and the recovery or restoration of the environment by corrupt individuals. For instance, perpetrators of environmental degradation may evade legal consequences due to weak legal frameworks, allowing them to avoid punishment. As a result, these offenders can escape justice and encourage the over-exploitation of resources due to their ability to evade the law. Furthermore, Pei et al. (2021) state that the formation of pro-environmental policies can be hindered by bribing policymakers. For example, the government could establish high regulations to target companies that produce high levels of pollution. Similarly, regulations can be crafted at the request and interest of companies by providing bribe compensation, ensuring that the regulations benefit them..

Sinha et al. (2019) found that corruption worsens environmental degradation by diminishing the positive effects of renewable energy and amplifying the negative impact of fossil fuels. Dincer & Fredriksson (2018) also noted that corruption increases carbon emissions. In developing countries, environmental protection is often deprioritized in favor of industrialization, sometimes due to corrupt practices (Sinha et al., 2019). While economic growth contributes to environmental degradation in Nigeria, corruption and internal conflicts help curb it by limiting investment (Usman et al., (2022). Additionally, Akalin et al. (2021) highlighted that corruption risks hindering the achievement of Sustainable Development Goals, particularly in newly industrialized nations aiming for growth without environmental harm (Demissew & Kotosz, 2019).

H2: Corruption influences CO2 emissions.

RESEARCH METHODOLOGY

To examine the relationship between variables in this study and in accordance with the characteristics of the data used, the method employed is quantitative. Panel data regression is applied to explain the main phenomenon in this research. To obtain valid and credible data,

secondary data is sourced from official websites. CO2 emissions and GDP per capita data are obtained from the World Bank, with the series codes for GDP per capita, PPP (in constant 2017 international dollars) and CO2 emissions (metric tons per capita), while corruption data is accessed from the Corruption Perception Index (CPI). The data used in this study is panel data, combining time series and cross-sectional data (Gujarati, 2003). The study covers the period from 2012 to 2018, focusing on ASEAN Member States.Table 1 presents the classification of models based on the form of government used in this study.

Table 1.
Classification of Country Forms in the Model

Country	Form of Government
Indonesia, Myanmar, Singapore, Laos, Vietnam, and the Philippines	Republican (1st Model)
Malaysia, Thailand, and Cambodia	Kingdom (2nd Model)

Eviews 12 Student Version was use to get the econometric model approach that will be used. Table 1 show the description of each variables in this study.

Table 2.
Description of each variables

Variable	Variable Operating Definition	Data Source
CO2 emissions	Carbon dioxide emissions are produced by burning fossil fuels and producing cement. Carbon dioxide emissions are generated during the consumption of solid, liquid, and gaseous fuels as well as gas combustion (Wang, et al, 2019).	World Bank website
Corruption Perception Index (CIP)	Corruption is the abuse of a situation that occurs by work in the public sector or is generally defined as the misuse of public resources for personal gain (Akhbari & Nejati, 2019).	Corruption Perception Index website
GDP per capita	GDP per capita is gross domestic product divided by the mid-year population (Wold Bank).	World Bank website

Source: World Bank and Corruption Perception Index website, (2022)

Furthermore, all the data is included in a regression model equation. However, because the data has different units, the data is first changed in the natural logarithm (*ln*), the coefficient value (βn), where is the error, i is for cross-section, and t is the time series. So that the following regression model equation is obtained: Furthermore, all the data is included in a regression model equation. However, because the data has different units, the data is first changed in the natural logarithm (*ln*), the coefficient value (βn), where is the error, *i* is for cross-section, and *t* is the time series. So that the following regression model equation is obtained:

Regression Equation Model: $lnCO2_{it} = \beta_0 + CPI_{it} + \beta_2 GDP_{it} + \varepsilon_{it}$

Description

β_0 : Constant

$lnCO2_{it}$: CO2 Carbon dioxide Emissions

$\beta_1 CPI_{it}$: Corruption Rate Index

$\beta_2 GDP_{it}$: GDP Per Capita

ε_{it} : error

Following the objectives, three models will be generated in this study. The first is an estimation model for countries with a republic form of government, the second is an estimation model for countries with a royal form of government, and the third is an estimation model for ASEAN member countries.

RESULT AND DISCUSSION

Results

Statistical Test Results

Estimation Model for a Country with a Republic Form of Government

This first estimation in model utilises secondary data from ASEAN countries with a republican form of government, such as Indonesia, Myanmar, Singapore, Laos, Vietnam, and the Philippines. The model aims to analyse the impact of GDP and corruption levels on CO2 emissions in these countries. Using a panel data approach, this analysis employs Fixed Effects and Random Effects regression techniques to understand the relationship between economic and environmental variables. The Fixed Effects Model estimation is also applied to capture specific effects that remain constant within each country, allowing control over unobserved factors that are stable over time. The data used is sourced from reputable institutions such as the World Bank and the Corruption Perception Index (CPI). The resulting model provides insights into how GDP and corruption levels influence environmental outcomes in ASEAN countries with a republican government system.

Table 3.
Model Determination Test

Model	Estimated Value	Terms	Decision
Chow Test.	Prob. 00.000	If P-Value<α (where α=0.10), then H0 is rejected.	Fixed Effect Model
Hausman Test.	Prob. 00.004	If P-Value<α (where α=0.10), then H0 is rejected.	Fixed Effect Model

Table 4.
Estimate *Fixed Effect Model*

Variable	Coefficient	Std. Error	t-Statistic	Prob.	Adjusted R-Square
C	-11.68778	3.958954	-2.952238	0.0057	0.980
CPI	0.028117	0.016669	1.686812	0.1008	
LNGDP	2.350495	0.465096	4.947407	0.000	

First Model: $\boldsymbol{lnCO2_{it} = -11.68778 + 0.028117 + 2.350495 + \varepsilon_{it}}$

Table 3 presents the First Model Determination Test analysis to determine the appropriate model. The significance value of 0.000 < 0.1 from the Chow and Hausman tests indicates that the Fixed Effect Model (FEM) meets the criteria and is suitable for application in this model. Table 4 shows the estimate *fixed effect model*, where corruption has a Prob. value of 0.1008 > 0.05, meaning that corruption does not contribute to or affect CO2 emissions. Meanwhile, different results are shown for the relationship between GDP per capita and CO2 emissions, with a Prob. value of 0.000 < 0.05, indicating a positive and significant relationship between the two variables. The R^2 value obtained is 0.980, meaning that the error value is relatively small.

Table 5.
Model Determination Test

Model	Estimated Value	Terms	Decision	
Chow Test.	Prob. 00.000	If P-Value<α (where α=0.10), then H0 is rejected.	Fixed Model	Effect
Hausman Test.	Prob. 00.004	If P-Value<α (where α=0.10), then H0 is rejected.	Fixed Model	Effect

Estimation Model for Countries with Royal Forms of Government

The second estimation model uses secondary data from ASEAN countries with a monarchical form of government, including Malaysia, Thailand, and Cambodia. This estimation model analyses the impact of GDP and corruption levels on CO2 emissions in these countries. Using a panel data approach, this analysis employs Fixed Effects and Random Effects regression techniques to understand the relationship between economic and environmental variables. The Fixed Effects Model estimation is also applied to capture specific effects that remain constant within each country, allowing control over unobserved factors that are stable over time. The data used is sourced from reputable institutions such as the World Bank and the Corruption Perception Index (CPI). The resulting model provides insights into how GDP and corruption levels influence environmental outcomes in ASEAN countries with a monarchical government system.

Based on the model test, the following results were obtained:

Table 6.
Model Determination Test

Model	Estimated Value	Terms	Decision	
Chow Test.	Prob. 00.000	If P-Value<α (where α=0.10), then H0 is rejected.	Fixed Model	Effect
Hausman Test.	Prob. 00.000	If P-Value<α (where α=0.10), then H0 is rejected.	Fixed Model	Effect

Table 7.
Estimate *Fixed Effect Model*

Variable	Coefficient	Std. Error	t- Statistic	Prob.	Adjusted R-Square
C	-8.243206	3.406364	-2.419943	0.0278	
CPI	0.040131	0.021330	1.881462	0.0782	0.996
LNGDP	1.937070	0.324033	5.977998	0.000	

Second Model : $\ln CO2_{it} = -8.243206 + 0.040131 + 1.937070 + \varepsilon_{it}$

Table 6 presents the Second Model Determination Test analysis to determine the appropriate model. The significance value of 0.000 < 0.1 from the Chow and Hausman tests indicates that the Fixed Effect Model (FEM) meets the criteria and is suitable for application in this model. Table 7 shows the Fixed Effect Model estimation, where corruption has a Prob. value of 0.0782 > 0.05, meaning that corruption does not contribute to or affect CO2 emissions. Meanwhile, different results are shown for the relationship between GDP per capita and CO2 emissions, with a a Prob. value of 0.000 < 0.05, indicating that GDP per capita contributes to the increase in CO2 emissions. The R^2 value obtained is 0.996, meaning that the error value is relatively small.

Estimation Model for ASEAN

The second estimation model uses secondary data from ASEAN countries consisting of nine countries, including Indonesia, Myanmar, Singapore, Laos, Vietnam, and the Philippines. Malaysia, Thailand, and Cambodia. Based on the model test, the following results were obtained:

Table 8.
Model determination test

Model	Estimated Value	Terms	Decision
Chow Test.	Prob. 00.000	If the probability value (P-Value) is less than the significance level = 10% H0 is rejected	Fixed Effect Model
Hausman Test.	Prob. 00.003	If the probability value (P-Value) is less than the significance level = 10% H0 is rejected	Fixed Effect Model

Table 9.
Estimate *Fixed Effect Model*

Variabel	Coefficient	Std. Error	t-Statistic	Prob.	Adjusted R-Square
C	-10.01669	2.546696	-3.933208	0.0002	0.987
CPI	0.034196	0.011502	2.973135	0.0045	
LNGDP	2.145326	0.295532	7.259199	0.0000	

Third Model: $\ln CO2_{it} = -10.01669 + 0.034196 + 2.145326 + \varepsilon_{it}$

Table 8 presents the Model Determination Test analysis to determine the appropriate model. The significance value of 0.000 < 0.1 from the Chow and Hausman tests indicates that the Fixed Effect Model (FEM) meets the criteria and is suitable for application in this model. Table 9 shows the Fixed Effect Model estimation, where the Prob. value is 0.0045 < 0.05, meaning that corruption has a positive and significant effect on CO2 emissions. Similarly, the relationship between GDP per capita and CO2 emissions shows a a Prob. value of 0.000 < 0.05, indicating that GDP per capita contributes to the increase in CO2 emissions. The R^2 value obtained is 0.987, meaning that the error value is relatively small.

The results of statistical tests using the Eviews tool show that in the regression model, there is no difference in the determinants of CO2 emissions by differentiating based on the shape

of the country. The same finding is that in republican countries, the factor that affects CO2 emissions is GDP per capita. In republican countries, corruption does not affect CO2 emissions, and only GDP per capita contributes. However, different findings based on statistical tests, namely when using all secondary data, the results of the determinant test show that corruption and GDP per capita significantly affect the increase in CO2 emissions even though the coefficient shows a relatively small value of 0.034196.

The same finding suggests that in republican countries, the factor influencing CO2 emissions is GDP per capita. In these countries, corruption does not affect CO2 emissions, with only GDP per capita contributing to the increase. However, different findings emerge when statistical tests are conducted using all secondary data. The results of the determinant test indicate that both corruption and GDP per capita significantly impact the increase in CO2 emissions, even though the coefficient value remains relatively small at 0.034196.

Discussion

Relationship of GDP on CO2

The estimation results from the first and second models show that there is no difference in the determinants of CO2 emissions based on the type of country, whether republican or monarchical. GDP per capita has a significant effect on CO2 emissions, which is consistent with the Environmental Kuznets Curve (EKC) hypothesis. This hypothesis states that, initially, economic activity tends to harm the environment based on static assumptions about environmental technology, preferences, and investment. However, as income increases, the demand for environmental improvements also rises.

Cowan et al. (2014) conducted a causality test, revealing a unidirectional causality from GDP to CO2 emissions in South Africa, and an inverse relationship between CO2 emissions and GDP in Brazil. Additionally, Sen & Abedin (2020) found that an increase in economic growth or GDP per capita, in the long run, would reduce environmental quality at a slower rate in China compared to India. These findings are consistent with the previous study by Demissew & Kotosz (2019), which showed a relationship between per capita income and CO2 emissions, serving as a proxy for environmental degradation. In other words, economic growth is positively correlated with CO2 emissions, meaning the higher the economic growth, the greater the increase in CO2 emissions. Although economic growth typically leads to environmental degradation in the early stages, it ultimately represents the best, and perhaps the only, way to achieve a sustainable environment.

In line with these findings, the third model of the regression estimation results using secondary data from the ASEAN Member States found similar results: GDP per capita affects increasing CO2 emissions. In line with the explanation above, it can be understood that these results indicate that each country in ASEAN initially explores resources to encourage economic growth, which will produce waste or CO2 emissions in the process. This waste can be in the form of pollution generated by factories in the production process, from transportation to human behavior that produces CO2 emissions to meet economic needs. It is known that every economic activity will produce emissions that will impact the environment, such as global warming.

Correlation of Corruption to CO2 Carbon Dioxide Emissions

The analysis of the first and second regression models shows no difference in the determinants of CO2 emissions between republican and non-republican countries. Statistical tests indicate that corruption does not have a significant impact on CO2 emissions, consistent with the findings of Arminen & Menegaki (2019), who also found that corruption was not significant in the three equation models examining economic growth, energy consumption, and air pollution. Other factors, such as global warming, may influence CO2 emissions.

These results indicate that corruption does not contribute to CO2 emissions, in line with the fact that all countries, both in the form of republics and kingdoms, are committed to achieving sustainable development goals by 2030. So that law enforcement at the government and stakeholder levels seeks to minimize corruption, especially in the scope of environmental damage, and strives to encourage and strengthen the main supporting factors for the achievement of the SDGs.

Model for ASEAN

Meanwhile, it differs from the results of statistical tests using sunder data for all ASEAN member countries. This finding is consistent with the research by Zhang & Chiu (2020) and Lee et al. (2020), which show that corruption increases pollution and CO2 emissions. This finding indicates that the higher the level of corruption, the stronger the increase in the shadow economy's effect on emissions—likewise, non-transparent policies abuse government authority regarding industrial policies that do not support environmental protection. Desai (1998) in Wang et al. (2019) found that in a case study of developing countries in Southeast Asia, companies bribed government officials in order to delay the legislative process of environmental protection laws and reduce the intensity of enforcement of existing environmental policies so that lead to high pollutant discharges. Furthermore, Liu & Dong (2020) state that countries with high incomes will prefer a ruling party that is not prone to corruption to significantly reduce pollution and create a more viable ecological environment. While low-income countries, the honest government will not significantly inhibit smoke pollution; instead, it appears to exacerbate a country's smog pollution.

CONCLUSIONS, LIMITATIONS, AND SUGGESTIONS

This paper examines the effect of GDP and corruption on CO2 emissions. The regression model is divided into three models by distinguishing the form of the Republic and the Kingdom, as well as a model with a sample of all members. ASEAN. We use the form of the country as a consideration to identify the factors that influence CO2 emissions. This step is used to enrich the research repertoire and distinguish it from previous research.

The study results show no differences in the determinants that affect the increase in CO2 emissions in republics and kingdoms. According to both regression models, only GDP per capita affects CO2 emissions, while corruption does not. This differs from the third model using ASEAN data, where both GDP per capita and corruption influence CO2 emissions. The EKC focuses more on a country's income than its shape, leading to different perceptions even if the countries are in the same region. The empirical findings of this study, based on the third model, show that GDP per capita and corruption influence the increase in CO2 emissions, although the impact of corruption is small.

The findings of this study highlight the influence of GDP per capita and corruption on CO2 emissions, underscoring the need for effective governance and policy interventions. While economic growth is crucial for national development, it must be pursued in a manner that minimises environmental degradation. To achieve this, governments should strengthen anti-corruption measures by enforcing stricter penalties, enhancing transparency, and improving regulatory oversight. Establishing independent monitoring bodies and adopting digital governance practices can help reduce corruption-related inefficiencies in environmental management. For policymakers, particularly in republics, it is essential to align economic policies with sustainable development goals. This includes implementing green investment incentives, enforcing stricter environmental regulations, and prioritising emission reduction programs. Furthermore, ASEAN nations should enhance regional cooperation by developing joint policies and shared frameworks for tackling environmental challenges. A collective approach can lead to more effective and long-term solutions for sustainable economic and environmental management.

This study has provided insights into the relationship between GDP, corruption, and CO2 emissions in ASEAN countries, but it is limited by the unavailability of data for Brunei, which prevented its inclusion in the analysis. To address this limitation, future research should explore qualitative methods such as case studies or expert interviews to examine Brunei's environmental policies and their impact. Additionally, researchers could analyse legal and regulatory frameworks across ASEAN nations to compare their effectiveness in controlling emissions. A broader dataset, including more years or additional environmental policy variables, would also enhance the robustness of future studies and provide a more comprehensive understanding of the factors influencing CO2 emissions in different governance systems.

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