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Analysis of the Effects of Renewable Energy Mix, Primary Energy Intensity, Population, and GDP per Capita on Greenhouse Gas Emissions in the Energy Sector in ASEAN Countries

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Abstract: This study aims to examine the effects of population, GDP per capita, primary energy intensity, and the renewable energy mix on greenhouse gas (GHG) emissions in the energy sector across ASEAN countries. A panel data regression analysis was conducted using the Fixed Effects Model (FEM) on annual data from ten ASEAN nations over the period 2000–2020. Robust standard errors clustered by country were applied to address issues of autocorrelation and heteroscedasticity. The results reveal that population growth and higher primary energy intensity are significantly associated with increased GHG emissions, while GDP per capita and the renewable energy mix do not show statistically significant effects. These findings indicate that energy efficiency and demographic trends are key drivers of emissions in the region. The novelty of this study lies in its use of panel econometrics to comprehensively assess multiple variables simultaneously within the context of ASEAN's energy sector, an area underrepresented in previous research. Practically, the results underscore the need for targeted energy efficiency improvements and integrated population-energy planning in policy formulation. This study contributes empirically to the discourse on sustainable energy transition and provides evidence-based insights for developing climate mitigation strategies tailored to the ASEAN context.

Keywords: ASEAN, Energy Intensity, Greenhouse Gas Emissions, Population, Renewable Energy

A. Introduction

The significant increase in Earth's temperature over the past century has elevated global climate change as one of the most urgent and critical challenges confronting humanity. Climate change is no longer a distant or future threat—it is a present and escalating crisis. According to the Intergovernmental Panel on Climate Change (IPCC) report published in 2023, the global average temperature has already risen by approximately 1.1°C above pre-industrial levels. If the current rate of greenhouse gas (GHG) emissions persists, projections suggest that the 1.5°C threshold could be exceeded by the mid-21st century. Crossing this critical limit would amplify the frequency and severity of climate-related disasters, including heatwaves, droughts, floods, and rising sea levels, all of which threaten ecosystems, human health, and global economic stability.

A primary contributor to global GHG emissions is the energy sector, which remains heavily reliant on fossil fuels such as coal, oil, and natural gas. International Energy Agency (IEA), in its 2022 report, emphasizes that this dependence on carbon-intensive energy sources plays a dominant role in driving emissions. Supporting this claim, data from ClimateWatch (2025) shows that emissions from the energy sector rose dramatically from 23,660.14 million tonnes of carbon dioxide equivalent ($MtCO_2e$) in 1990 to 38,008.54 $MtCO_2e$ in 2022. This sharp increase reflects the rising global energy demand, fuelled by industrialization, urbanization, and population growth.

While these trends are global, their consequences and dynamics are particularly pronounced in developing regions, where economic expansion and infrastructure development tend to rely more heavily on fossil fuels. This is especially relevant in Southeast Asia, where countries are experiencing rapid economic growth and urbanization, leading to increased energy demand and associated emissions (H. M. Nguyen & Nguyen, 2018;Y. Wang et al., 2016). The ASEAN region—comprising ten diverse yet interconnected nations—stands out due to its unique mix of developmental challenges, high energy dependency, and emerging climate policies.

Previous studies have explored the complex interconnections between energy consumption, energy mix, economic growth, and greenhouse gas emissions. Research by Lu (2017) and Suri et al. (2025) reveals that economic expansion tends to drive up energy consumption, which, in the absence of a shift toward cleaner sources, results in greater emissions. The composition of a country's energy mix—particularly the proportion of renewable versus non-renewable sources—plays a critical role in determining environmental outcomes. These findings emphasize the need to reassess energy policy frameworks and to accelerate the transition to low-carbon alternatives. However, there remains a significant research gap in understanding how key variables such as population growth, GDP per capita, primary energy intensity, and renewable energy share collectively influence energy-related GHG emissions in the ASEAN region. Most prior studies have primarily focused on developed economies, whose regulatory frameworks, technological capacities, and economic profiles differ markedly from those of developing nations. ASEAN presents a unique case marked by heavy dependence on fossil fuels, high rates of urbanization, and rapid economic growth (International Energy Agency, 2023). Moreover, the impacts of clean energy initiatives remain limited in this region due to the early stage of energy transitions across most ASEAN countries.

Improving the transition to cleaner energy is further complicated by ASEAN's recent energy trends. Fossil fuels continue to dominate the region's energy mix, and energy consumption has nearly doubled in the last two decades (International Energy

Agency, 2023). Meanwhile, data from ASEANstats (2025) reveals that the region's population is large, reaching 677.6 million people in 2023, and rising GDP per capita—particularly in countries like Vietnam—is placing additional pressure on the energy system, further driving up GHG emissions (H. T. Nguyen et al., 2022). Despite modest efforts in renewable energy development and efficiency improvements, these have not yet yielded sufficient results to reverse the rising emissions trajectory. To align with the Paris Agreement, the IEA recommends increasing clean energy investment by up to five times (Reuters, 2024).

This study addresses the identified research gap by employing a panel data approach to conduct a comprehensive empirical analysis of ASEAN countries, an approach that has been largely underutilized in existing literature. Unlike prior research that typically isolates one or two determinants, this study simultaneously examines four key variables: (1) the renewable energy mix, (2) primary energy intensity, (3) population, and (4) GDP per capita. This multidimensional approach, using panel data that spans both temporal and cross-country variation, offers a more robust and region-specific understanding of the dynamics influencing GHG emissions in the energy sector.

The novelty of this study lies in its use of panel data analysis, which allows for a more nuanced capture of heterogeneity across ASEAN countries. This method advances the literature by enabling an exploration of both within-country changes over time and between-country differences—elements often overlooked in cross-sectional or time series only studies. By doing so, this research contributes valuable insights into how demographic, economic, and energy-related factors interact to shape emission outcomes in one of the world's most dynamic and rapidly developing regions. The specific objectives of this study are as follows:

1. To analyze the impact of the renewable energy mixes on GHG emissions in the ASEAN energy sector;
2. To analyse the influence of primary energy intensity on energy-related GHG emissions;
3. To analyze how population affects energy-related GHG emissions; and
4. To analyze the role of GDP per capita in shaping energy-related GHG emissions.

Based on this context, the core research question addressed by this study is: How do the renewable energy mix, primary energy intensity, population, and GDP per capita affect greenhouse gas (GHG) emissions in the ASEAN energy sector? By answering this question, the study seeks to provide empirical evidence that supports the formulation of effective, targeted, and context-appropriate energy policies for ASEAN countries—policies that not only aim to reduce emissions but also foster sustainable development in line with each country's capacities and socio-economic conditions.

B. Methods

This study adopts an explanatory research design using a quantitative approach to analyse the causal relationships between selected variables. The quantitative method allows researchers to measure variables numerically, facilitating objective and statistical analysis to examine patterns, trends, and causal linkages systematically. This approach is particularly relevant for exploring how renewable energy mix, energy intensity, population, and GDP per capita influence greenhouse gas (GHG) emissions in ASEAN's energy sector.

This study employs panel data regression analysis, which combines time series and cross-sectional data. Panel data analysis enables the observation of both temporal dynamics and inter-country variation, allowing for deeper insights into heterogeneous effects across countries (Hsiao, 2014). Specifically, this study uses data from ten ASEAN member countries—Indonesia, Malaysia, Thailand, Vietnam, the Philippines, Singapore, Brunei Darussalam, Laos, Myanmar, and Cambodia—spanning a 21-year period from 2000 to 2020. The panel is balanced, with a consistent set of observations for each country across all years. The analysis uses Stata version 17, which supports advanced econometric modelling and assumption testing.

This study draws upon one conceptual framework, the IPAT identity (Impact = Population × Affluence × Technology). The IPAT identity explains environmental impact as a function of population size, economic activity, and technology. In this study, population and GDP per capita represent the population and affluence components, respectively. Since direct measures of technology are not available, the study uses renewable energy mix and primary energy intensity as proxies—renewable energy mix reflects cleaner technological adoption, while lower energy intensity indicates improved energy efficiency (Degirmenci et al., 2024).

Type of Study

This study adopts an explanatory research design. Explanatory research seeks to investigate and explain causal relationships among variables (Sainani, 2014). The dependent variable in this study is greenhouse gas (GHG) emissions from the energy sector, measured in metric tons of CO_2 equivalent ($MtCO_2e$), while the independent variables include:

1. Renewable energy mix (percentage of renewable energy in total energy consumption);
2. Primary energy intensity (energy consumption per unit of GDP);
3. Population (in millions); and
4. GDP per capita (in constant 2015 USD)

A detailed table of operational definitions is provided below:

Variable	Definition	Unit
GHG emissions	Emissions from the GHG's energy sector	$MtCO_2e$
Renewable energy mix	Share of renewables in total final energy consumption	Percentage (%)
Primary energy intensity	Energy use per unit of GDP	MJ/$2017 PPP GDP
Population	Total national population	Millions
GDP per capita	Economic output per person, adjusted to constant 2015 USD	USD

Research Procedure

Data Collection

This study relies entirely on secondary data obtained from reputable sources. The data sources and their corresponding variables are:
1. Climate Watch (Energy-related GHG emissions, accessed in 2025)
2. World Bank (renewable energy mix, primary energy intensity, GDP per capita, and population data, accessed in 2025)

These ten ASEAN countries were selected based on the availability of complete data across the entire study period. This regional sample reflects a wide range of energy profiles and stages of economic development, allowing for comprehensive comparative analysis.

Data Processing and Analysis

Following data collection, the data were processed and analyzed using panel data regression in Stata version 17. Model selection was guided by the following diagnostic tests:
1. The Chow Test, which is used to determine whether the most suitable panel data regression model is the Fixed Effect Model (FEM) or the pooled Ordinary Least Squares (OLS) model (Binkley & Young, 2022). In this case, the Chow test result showed a Prob > F value of less than 0.05, indicating that the Fixed Effect Model is more appropriate than pooled OLS for this study.
2. The Hausman Test, which is used to choose between the Fixed Effect Model (FEM) and the Random Effect Model (REM) (Baltagi & Liu, 2016). The results from this test showed a Sargan-Hansen statistic of 72.65 with a p-value of 0.0000, which is also less than 0.05. This indicates that the Random Effect Model is inconsistent and that the Fixed Effect Model is the more suitable choice for this research.

Classical assumption tests included:
1. Normality Test of the residuals, using the Shapiro-Wilk Test, showed that the residuals do not follow a normal distribution (p-value = 0.000). This is a common

occurrence in panel data analysis and does not invalidate the results as long as a robust model is applied.

2. Heteroskedasticity Test, using the Modified Wald Test, revealed the presence of heteroskedasticity (p-value = 0.000), which means that the variance of residuals is not constant across observations.
3. Autocorrelation Test, using the Wooldridge Test, indicated the presence of autocorrelation in the data (p-value = 0.0002), which can lead to inefficient coefficient estimates.
4. Multicollinearity Test, using the Variance Inflation Factor (VIF), showed that all independent variables had VIF values below 10 (average VIF = 1.77), suggesting that there is no serious multicollinearity that would distort the regression results.

To correct for autocorrelation and heteroskedasticity, the Fixed Effect Model was estimated using robust standard errors clustered by country. This method increases the reliability of coefficient estimates by accounting for within-country serial correlation and variance inconsistency over time.

Interpretation and Reporting of Results

The final phase of the analysis involved interpreting the regression outputs. Each independent variable's coefficient was assessed in terms of statistical significance, direction (positive/negative), and magnitude of effect on GHG emissions in the energy sector. This interpretation aims to uncover how renewable energy adoption, energy efficiency, population changes, and economic growth influence emissions in the ASEAN energy sector.

These insights form the empirical foundation for the study's policy recommendations, supporting the development of targeted and effective environmental policies that align with ASEAN countries' socio-economic contexts and emission reduction goals.

C. Results and Discussion

Regression Results

The table below presents the regression results using a fixed effects model with robust standard errors clustered by country:

Variable	Coefficient	Robust Std. Error	t-Statistic	P-Value	Significance
Renewable Energy Mix (%)	-1.01847	0.86753	-1.17	0.271	Not significant
Primary Energy Intensity (MJ/USD)	6.62073	2.66523	2.48	0.035	Significant
Population (million)	0.00000545	0.000000942	5.79	0.000	Significant
GDP per Capita (USD)	0.0008319	0.000654	1.27	0.235	Not significant

The model yields an overall R-squared value of 0.7919, indicating that approximately 79.19% of the variation in greenhouse gas (GHG) emissions in the energy sector is explained by the independent variables.

Discussion

Renewable Energy Mix

The coefficient of the renewable energy mix is -1.01847, implying a negative relationship with energy-related GHG emissions. However, the result is statistically insignificant ($p = 0.271$), suggesting that variations in the renewable share of total energy consumption do not have a discernible impact on energy sector emissions in ASEAN over the period analysed. This finding aligns with the work of Apergis et al. (2010), who noted that renewable energy's impact on emissions is often muted without parallel infrastructure support or scaling.

Primary Energy Intensity

Primary energy intensity shows a statistically significant and positive effect on energy-related GHG emissions ($\beta = 6.62073$, $p = 0.035$), indicating that higher energy consumption per unit of GDP is associated with higher emissions. This reinforces the idea that energy inefficiency is a key driver of environmental degradation in ASEAN, in line with studies by Al Mamun et al. (2025).

Population

Population growth exerts a significant positive influence on energy-related GHG emissions ($\beta = 0.00000545$, $p = 0.002$). Despite the seemingly small numerical value, a 1 million increase in population corresponds to a 0.00000545 $MtCO_2e$ rise in emissions from the energy sector, assuming other factors remain constant. This is consistent with the IPAT identity, where increased population leads to higher aggregate energy demand.

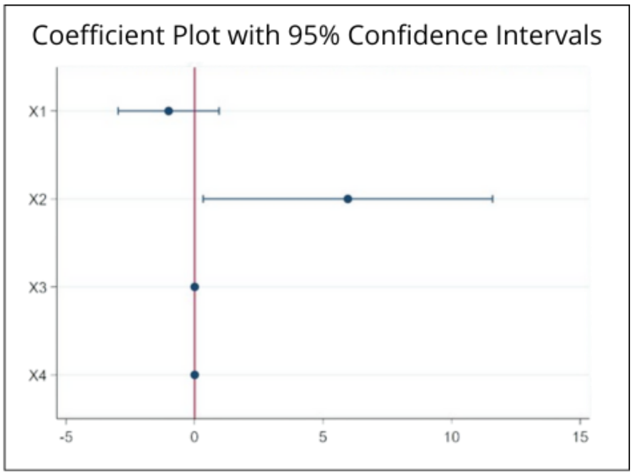
GDP per Capita

GDP per capita demonstrates a positive but statistically insignificant relationship with energy-related GHG emissions ($\beta = 0.0008319$, $p = 0.235$). This finding deviates from the Environmental Kuznets Curve (EKC) hypothesis, which posits that emissions rise with income until a turning point is reached, after which they decline as economies adopt cleaner technologies. The result suggests that economic growth in ASEAN has yet to decouple from emissions, indicating that per capita income does not yet reflect a green transition.

Graphical Representations

To complement the regression analysis, this section presents several visualizations that help illustrate the relationships between the independent variables and greenhouse gas (GHG) emissions in the energy sector across ASEAN countries. These graphs provide a more intuitive understanding of the data and support the interpretation of the results.

Coefficient Plot



This coefficient plot displays the estimated effect (coefficient) of each independent variable—renewable energy mix, primary energy intensity, population, and gdp per capita—on GHG emissions in the energy sector, along with 95% confidence intervals.

1. If the horizontal line (confidence interval) crosses zero, it means the effect of that variable is statistically insignificant.
2. In this graph, we see that renewable energy mix and GDP per capita have confidence intervals that cross the zero line, meaning their effects are not statistically significant.
3. On the other hand, primary energy intensity and population have intervals that lie entirely on the positive side, which aligns with our earlier finding that these two variables significantly increase emissions.

This plot visually confirms the regression output and helps quickly identify which variables matter most in explaining emission patterns in the ASEAN energy sector.

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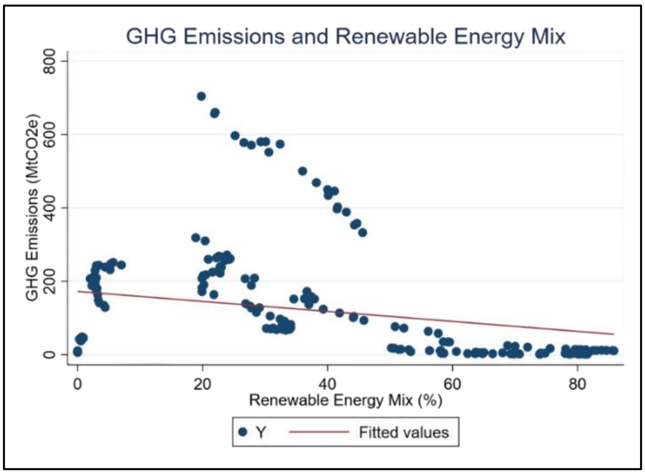
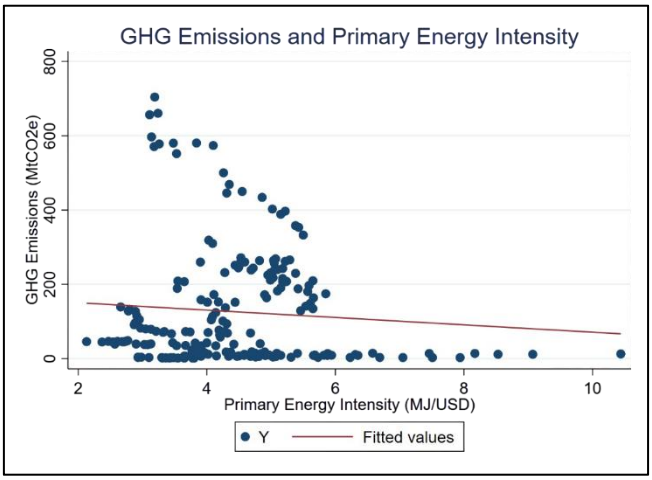
Scatter Plot: GHG Emissions and Renewable Energy Mix (X1)



This scatter plot shows the relationship between the share of renewable energy in the total energy mix and GHG emissions in the energy sector. The pattern of dots appears fairly scattered with no strong upward or downward trend.

1. This supports the regression finding that there is no significant relationship between the renewable energy mix and emissions in the ASEAN context.
2. It suggests that while countries may be adopting more renewables, it hasn't been enough to reduce overall emissions, likely because fossil fuels still dominate energy production.

Scatter Plot: GHG Emissions vs Primary Energy Intensity (X2)

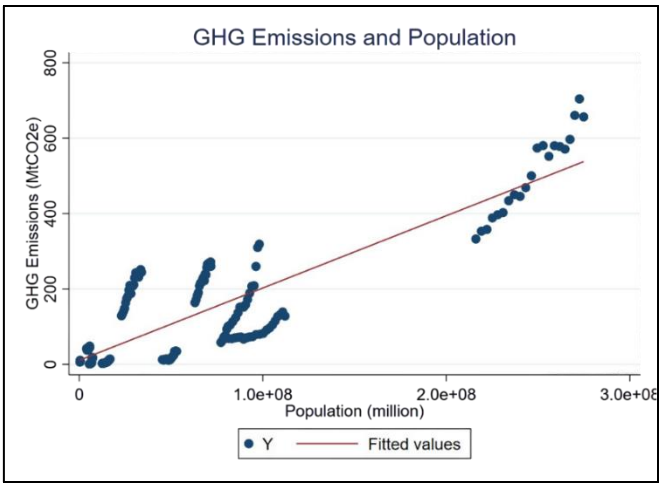


This scatter plot reveals a clear positive trend between primary energy intensity (measured as energy used per unit of economic output) and energy-related GHG emissions.

1. The upward slope of the dots suggests that as countries use more energy to produce one unit of GDP, their emissions also increase.

2. This strong and visible pattern supports the statistically significant regression result.
3. It shows that inefficient energy use is a major contributor to emissions in the region, and improving energy efficiency can play a key role in reducing emissions.

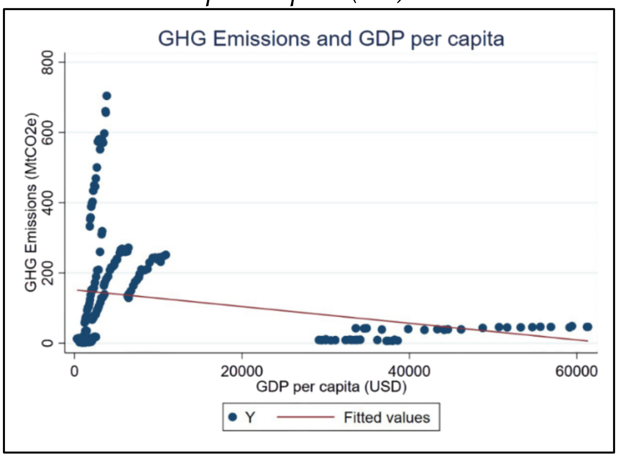
Scatter Plot: GHG Emissions vs Population (X3)



This plot shows a positive and relatively strong correlation between population size and energy-related energy-related GHG emissions.

1. Countries with larger populations tend to have higher emissions from the energy sector.
2. This is expected, as more people generally means greater demand for electricity, fuel, and infrastructure—all of which increase energy use and emissions.
3. The result supports the regression finding that population has a significant effect on emissions and highlights the importance of integrating demographic trends into climate and energy planning.

Scatter Plot: GHG Emissions vs GDP per Capita (X4)



This scatter plot displays the relationship between income per person (GDP per capita) and energy-related GHG emissions.

1. The pattern here is less clear, with a slight upward trend but no strong relationship.
2. This aligns with the regression result, which showed a positive but statistically insignificant relationship.
3. It implies that economic growth in ASEAN has not yet led to a consistent reduction or increase in emissions across countries. This may be due to the fact that many ASEAN economies are still in the development phase, where growth is often tied to industrial expansion and higher energy use.

Comparison with Previous Studies

To provide context and support for this study's findings, the following table presents a comparison with previous empirical studies on the effects of renewable energy, energy intensity, population, and GDP per capita on greenhouse gas emissions:

Study	Variable	Significance	Direction	Context
This Study	Renewable energy mix to energy-related GHG	Not significant	Negative	ASEAN (2000–2020)
Qing et al. (2023)	Renewable energy (electricity) to energy-related GHG	Significant	Negative	BRICS (2000-2019)
Khan et al. (2019)	Renewable energy to GHG emissions	Significant	Negative	34 high-income countries from Asia, Europe and America (1995-2017)
Qiao et al. (2019)	Renewable energy to GHG emission (CO2)	Significant	Negative	19 nations of the G20 countries (1990-2014)
Chien et al. (2023)	Renewable energy consumption to GHG emissions	Significant	Negative	ASEAN (2006 – 2020)
This Study	Energy intensity to energy-related GHG	Significant	Positive	ASEAN (2000–2020)
Lu (2017)	Energy intensity to GHG emissions	Significant	Positive	16 Asian countries (1990-2016)
Al Mamun et al. (2025)	Energy intensity to GHG emission (CO2)	Significant	Positive	106 middle-income countries (1980-2022)
S. S. Wang et al. (2011)	Energy intensity to GHG emission (CO2)	Significant	Positive	China (1995-2007)
Saboori & Sulaiman (2013)	Energy intensity to GHG Emission (CO2)	Significant	Positive	5 ASEAN countries (1971-2009)
This Study	Population to energy-related GHG	Significant	Positive	ASEAN (2000–2020)
Zhang et al. (2021)	Population to GHG (industrial and residental)	Significant	Positive	21 European countries (2007-2017)
Kolasa-Więcek et al. (2023)	Population to GHG emissions	Significant	Negative	16 European countries (1995-2021)

Dong et al. (2018)	Population to GHG emission (CO2)	Significant	Positive	128 countries (1990-2014)
Begum et al. (2015)	Population growth to GHG emission (CO2)	Not significant	Positive	Malaysia (1970-2009)
This Study	GDP per capita to energy-related GHG	Not Significant	Positive	ASEAN (2000–2020)
Jianu et al. (2022)	GDP per capita to GHG emissions per capita	Significant	Positive	EU-27 member states (2010-2019)
Lyeonov et al. (2019)	GDP per capita to GHG emissions	Significant	Positive	EU countries (2008-2016)
Aslam et al. (2021)	GDP per capita to GHG emission (CO2)	Significant	Positive	China (1962-2018)
Abdullah (2023)	GDP per capita to GHG emission (CO2)	Significant	Positive	ASEAN (1995-2021)
Ahmad et al. (2024)	GDP per capita to GHG emission (CO2)	Significant	Positive	Indonesia (1990-2021)

This study found a negative but statistically insignificant relationship between renewable energy mix and energy-related GHG emissions in ASEAN. In contrast, studies by Qing et al. (2023) on BRICS, Khan et al. (2019) on high-income countries, and Qiao et al. (2019) on G20 nations showed a significant negative impact, suggesting that renewable energy helps lower emissions. Chien et al. (2023) similarly found significant short- and long-term reductions in emissions from renewable energy in ASEAN. These differences may be due to variations in renewable energy capacity, efficiency, or policy implementation.

The positive and significant relationship between energy intensity and energy-related GHG emissions found in this study aligns with Lu (2017), who showed a strong link across 16 Asian countries, and Al Mamun et al. (2025), who found similar results in 106 middle-income countries. S. S. Wang et al. (2011) highlighted the role of energy consumption in China's long-run emissions, while Saboori & Sulaiman (2013) observed that energy intensity contributed significantly to emissions in ASEAN. These findings emphasize the urgent need for improving energy efficiency across the region.

This study also confirms that population growth significantly raises emissions, in line with findings by Dong et al. (2018) and Zhang et al. (2021). However, results are not uniform— Begum et al. (2015) reported no significant effect in Malaysia, and Kolasa-Więcek et al. (2023) found a negative population-emissions link in some European countries. These variations suggest that the impact of population may depend on demographic structure, energy access, and urbanization levels.

Finally, this study found that GDP per capita has a positive but insignificant effect on emissions in ASEAN, differing from most previous studies. Jianu et al. (2022), Lyeonov et al. (2019), and Aslam et al. (2021) showed that rising income increases emissions in the EU and China. Abdullah (2023) found mixed effects across income levels, while Ahmad et al. (2024) confirmed a strong positive impact in Indonesia. These differences indicate that economic development's environmental impact varies by stage and structure of growth.

Policy Implications and Structural Limitations

This study highlights the urgency of improving energy efficiency in ASEAN. Given the significant impact of energy intensity on emissions, regulations, cleaner technology incentives, and regional collaboration are essential. As Zhu et al. (2019) and Al Mamun et al. (2025) emphasize, renewable energy alone is insufficient without supportive policies such as carbon pricing to effectively reduce emissions.

Population growth significantly drives emissions, especially through urban energy demand. Therefore, integrating demographic trends into energy policy is crucial. Planning for sustainable housing and public transit can help, particularly in developing economies that have not yet reached income levels where emissions start to decline, as shown by Satici & Cakir (2021).

The transition to renewable energy must also overcome structural barriers. As Suri (2025) explains, outdated grids and limited storage capacity reduce the benefits of renewables and can even increase pollution. Jacobson & Delucchi (2011) further argues that political and social challenges are more pressing than technical or economic ones in achieving clean energy goals.

Finally, the mix of renewable sources matters. Bett & Thornton (2016) found that a 70:30 solar-to-wind ratio can enhance energy stability. Ahiduzzaman & Islam (2011) also showed that solar and biomass are viable in regions with the right conditions. To ensure success, ASEAN nations must back renewable investments with strong policies and institutional reforms, as the Paris Agreement alone has proven insufficient (Al Mamun et al., 2025).

D. Conclusion

Based on panel data analysis of ten ASEAN countries during the period 2000–2020, it can be concluded that primary energy intensity (coefficient: 6.62073; p = 0.035) and population (coefficient: 0.00000545; p = 0.000) have a positive and significant impact on greenhouse gas (GHG) emissions in the energy sector. This indicates that higher energy consumption per unit of GDP and population growth are key drivers of emission increases. In contrast, the renewable energy mix (coefficient: -1.01847; p = 0.271) and GDP per capita (coefficient: 0.0008319; p = 0.235) do not show a statistically significant impact, although the negative direction of the renewable energy mix coefficient suggests a potential tendency to reduce emissions. Thus, only primary energy intensity and population are statistically proven to influence GHG emissions in the energy sector across ASEAN countries.

Policy Recommendations: In light of the study's findings and structural challenges identified in the discussion, the following policy recommendations are proposed to reduce greenhouse gas emissions in ASEAN’s energy sector:

1. Strengthen energy efficiency policies through regulatory standards, fiscal incentives, and education campaigns, targeting sectors with high energy intensity to achieve immediate emission reductions.
2. Incorporate demographic trends into energy strategies by aligning urban planning, housing, and public transport development with population growth patterns to curb future energy demand.
3. Upgrade energy infrastructure by investing in smart grids and storage systems to maximize the impact of renewable energy and address variability, especially in coal-dependent areas.
4. Implement carbon pricing and phase out fossil fuel subsidies to reflect the true environmental cost of emissions and incentivize low-carbon technologies.
5. Enhance regional cooperation to pool technical expertise, share policy experiences, and mobilize joint financing for clean energy transitions across diverse national contexts.

This study is limited to emissions arising solely from the energy sector, excluding other significant sources such as land use, agriculture, and transportation. Additionally, data availability and quality vary across ASEAN countries, potentially affecting the accuracy and comparability of the panel data estimations. The methodological approach also uses a static panel model, which does not capture dynamic relationships or possible spatial interdependencies between countries that might influence emissions.

Future studies could benefit from adopting dynamic panel models, such as the Generalized Method of Moments (GMM), to better capture the effects of past emissions and economic activity on current outcomes. Incorporating spatial econometric methods could also reveal the presence of cross-border influences or spill over effects in energy consumption and emissions. Broadening the analysis to include additional sectors, such as transportation and land use, as well as variables like technological innovation and institutional quality, would provide a more comprehensive understanding. Lastly, conducting in-depth case studies on individual ASEAN countries could help uncover country-specific factors and offer tailored policy insights.

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