The Impact of Economic Growth on Carbon Emission in ASEAN

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Abstract. The tension between rapid economic expansion and environmental degradation remains a critical discourse within the Association of Southeast Asian Nations (ASEAN). This study investigates the dynamic impact of economic growth on CO_2 emissions across nine ASEAN economies from 1990 to 2022, whilst controlling for trade openness, ecological footprint, natural resource rents, and government expenditure. This study used a Pooled Mean Group (PMG) estimator in a Panel ARDL framework, which enabled it to handle problems of confounding and heterogeneity. The actual finding shows that economic growth increases carbon dioxide emissions in both the short run and long run. It implies, for example, that Kunming is possible in the kink shape upward hump of the environmental curve. Furthermore, whilst ecological footprint intensifies environmental pressure, the findings offer a nuanced perspective: trade openness, natural resource rents, and government expenditure serve as significant mitigating factors that reduce long-term emissions. This implies that international integration and fiscal policy can facilitate a transition towards sustainability. Consequently, the study posits that ASEAN policymakers must move beyond growthcentric paradigms by leveraging green fiscal reforms and technology transfer through trade to decouple economic progress from ecological degradation.

Keywords: Carbon Emission, Economic Growth, ASEAN, ARDL Approach.

1 Introduction

Climate change issues have increasingly come under the international spotlight in recent years, not least with the creation of the United Nations 17 Sustainable Development Goals in 2016, some of which are intrinsically tied to the environment. The burning of outdated energy sources, especially coal and oil, has had a serious impact on the quick rise of the greenhouse gas emissions, resulting in noticeable damage to the environment. There are numerous researches and studies indicate that CO_2 discharge grows by 1.9percentage each year, which relies on non-renewable kinds of energy sources [1, 2]. Hence, factors limiting energy consumption and CO_2 emissions have been an enduring subject of research, since if effective measures to curb global warming are to be developed, it first needs to be recognised that emissions are raised not just by growth, development and consumption of energy but also by liberalization of trade [2].

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Numerous studies have demonstrated a strong relationship between increasing energy use and economic growth [3]. Economic growth itself serves as an essential macroeconomic indicator reflecting national welfare [4], income inequality among countries [5], and the standard of living of the population [6]. However, recent robust economic expansion has sparked growing concern about how to balance economic progress with environmental preservation [7]. This trade-off arises because non-renewable natural resources remain central to production processes, and the mismanagement of material utilization leads to environmental degradation [8].

The tension between economic growth and environmental conservation continues to dominate academic debates, especially in developing regions such as the Association of Southeast Asian Nations (ASEAN) [9], [10], [11]. Although most ASEAN countries have experienced a slowdown in economic expansion, environmental challenges have intensified, as reflected in rising CO_2 emissions [12], [13]. The Fourth Industrial Revolution, technological innovation, and digital transformation have supported economic growth in the region, yet they have also fueled greater energy demand, particularly in low-income economies, increasing the risk of higher carbon emissions [14]. Given this context, a comprehensive assessment of the relationship between economic growth and CO_2 emissions within ASEAN is both relevant and necessary.

This study uses the dataset of GDP to analyze the impact of GDP on CO_2 emissions among ASEAN member countries. This paper consists of two sections, at the same time, while trade openess, ecologgical impact, nature resource rents, peopulation and government expenditure will also be counted. Second, despite a long tradition of timeseries and panel studies exploring the growth–emission nexus [15, 16, 17], our understanding of how it operates is relatively sparse. One particular exception is ASEAN, which occupies a key position within the interlocked spheres of global economy and environment. Second, the panel Autoregressive Distributed Lag (ARDL) approach is used in this study. It focuses on testing the cross-sectional dependence, stationarity and cointegration problems and thereby, essentially seeking shortand long-term relationships between economic growth and CO_2.

The empirical results provide robust evidence that economic growth exerts a significant and persistent positive impact on CO_2 emissions across ASEAN countries, suggesting that the current pattern of growth remains environmentally unsustainable and underscoring the need to integrate sustainability into regional development policies.

2 Literature Review

Researchers Saboori, B., and Sulaiman, J. [15] in their previous work analysed with ARDL panels energyconsumption, economic growth and CO 2 emissions. The scope of this research is limited to five ASEAN countries which are contained in Indonesia, Malaysia, Philippines, Singapore, and Thailand. Therefore, further research is required to ascertain the extent macro investment determinant explains CO2 emissions due to the economic growth factor in ASEAN countries in2014. This paper analyses the carbon dioxide emissions and economic growth nexus, based on data from eight ASEAN countries for the period 1994 through 2018. We use the ARDL panel approach to compute the short-run and long-run impacts of research problems to give a new chapter to the existing academic literature.

Scholars continue to debate the interaction between economic activity and environmental quality. Many studies identify a positive correlation between economic growth and CO_2 emissions, suggesting that expansion in economic activity increases environmental pressure. However, other research supports a non-linear relationship, indicating that after reaching a certain threshold, further economic growth can reduce emissions through structural change and technological advancement. Shan, A. et al. [18] found that while economic growth negatively impacts the environment, fiscal decentralization exerts a nonlinear influence in reducing CO_2 emissions, implying that balanced growth and efficient resource utilization enhance environmental quality.

Environmentally harmful economic activities aggravate both welfare conditions and ecological degradation [19]. Evidence from the Middle East and North Africa (MENA) region supports this view, showing that industrialization, trade, energy consumption, and urbanization contribute to long-term environmental harm [20]. In contrast Shaw,

D. et al. [21] revealed that higher income levels may foster environmental improvements through greater investment in pollution control and cleaner production.

Increased revenue enables more investment in research and development (R&D), facilitating technological innovation for pollution management. Wang, Q., Zhang, F. [22] found that in BRICS countries, higher R&D expenditure helps decouple economic growth from environmental degradation. Yet, Yang, N., et al. [23] observed that despite China's rapid technological advancement, its impact on reducing industrial emissions remains limited, as current innovations cannot offset the environmental pressures of industrial expansion. Environmental regulations can mitigate emissions, but they may not counteract the industrial sector's growth stimulus.

Although it may imperil some immediate economic development, the complete prohibition on the use of coal, oil and natural gas in the industrialized nations is a uniformly successful anti-production policy. Saboori and Sulaiman [15] confirmed that low-income countries that rely entirely on fossil fuels for their energy needs will undoubtedly face pollution. Yes, a recently published paper by Namahoro, J., et. al. In East Africa,

[24] found evidence of a negative link between alternative energy consumption and CO_2 emissions suggesting that the shift to other forms of power generation enhances sustainability.

Heidari H. et al [10]. used similar methodologies to compare economic growth, CO_2 emissions and energy consumption in Malaysia, Indonesia, the Philippines, Singapore and Thailand. Initially, even some standard stabilization levels are exceeded by CO_2 emissions, but they subsequently fall below trend for low and mid range As co per capita. The average per capita real GDP growth (a.k.a. GDP per capita growth) in the ASEAN countries for 2018 was ysualy larger than 5% according to an ASEAN Secretariat survey [12]. Similarly, Saboori, B., Sulaiman, J. [15] applied the ARDL panel approach to analyze the growth–energy–emission nexus for five ASEAN economies. Building upon these findings, the present study extends the analysis to eight ASEAN countries over the period 1994–2018, using a panel ARDL framework to examine both shortand long-term effects of economic growth on CO_2 emissions.

3 Data and Methodology

This study employs panel data from ASEAN member states, concentrating on nationallevel information from 1990 to 2022 to examine the influence of economic growth on carbon emissions. The data sources comprise the Global Carbon Budget, Global Footprint Network the World Bank. This study employs panel data from ASEAN member nations, concentrating on national-level data from 1990 to 2020, to examine the impact of economic growth on carbon emissions.

Data were based on a variety of sources: Global Carbon Budget, Global Footprint Network and, from World Development Indicators WDI data provided by World Bank. We employed panel data to exchange more information, more options, less collinearity between ourdependent variables, more degrees of freedom, and a more efficient parameter value estimation. Data gave us no other choice as to what to study, and where, and whole countries by carbon-dioxide emission padded our study time. As Myanmar was one of the nations that were too difficult to interpomate to and do not have good demographics according to the five principles of correct data collection their data are missing– we will concentrate on the other nine ASEAN member nations.

The study examines the independent and dependent variables, and in this paper, we include some additional variables which deter carbon dioxide emissions. Drawing from the reviewed literature, this article controlled for trade openness, ecological footprint, natural resources rents, population and government expenditure. Table 1 in the next section lists the variables and data sources employed.

Table 1. Variables Used in Model

Variable	Variable Name	Variable Description	Sources
Dependent Variable	CO2	Carbon Emission (Tonnes)	Global Carbon Budget
Independent Variable	GDP	Gross Domestic Product (PPP, Constant 2017 International $)	World Bank
Control Variable	TR	Sum of Export and Import to GDP	World Bank
	EF	Ecological Footprint (GHA)	Global Footprint Network
	NRR	Natural Resources Rents	World Bank
	POP	Total of Population	World Bank
	GOV	Government Expenditure ($)	World Bank

Source: author's work based various sources

Panel data constructing ARDL model was development based on this premise. It allows for one-time testings of both infrequent modifications and parts of lasting compel. One type of model has unique benefits over another. It allows linked orders of integration, is applicable to all variable and can take a common structure to characterize between ec, between econometricvaribles across time. Estimation model from ARDL Panel data as the following:

$$\Delta LnCO2_{it} = \varphi_i \left(LnCO2_{i,t-1} - \beta_i' X_{it}\right) + \sum_{j=1}^{p-1} \alpha^*_{ij} \Delta lnCO2_{i,t-j} + \sum_{j=0}^{q-1} \vartheta^*_{ij} \Delta X_{i,t-j} + \mu_i + \varepsilon_{it} \quad (1)$$

In this application, β_i is a vector that measures the long-term impacts of independent variables, such as Economic Growth (GDP), the principal variable of interest, in conjunction with other control variables, on the growth rate of carbon emissions. Simultaneously, φ_i functions as an error correction method. The terms that remain capture the transient response. The independent source of the disturbances is time. They all have zero mean and constant variance. Apply ARDL Method,It consist many critical steps such as residual stationarity test; cointegration test; Hausman Test,"Can variables interact or not?"; and whether we are using Pooled Mean Group (PMG) estimation, Mean Group (MG) estimates will be used or we utilize dynamic fixed-effect Panel ARDL estimation.

4 Results of the Research

Table 2 present the summary statistics of the variables included in the investigation, offering insights into their distributional attributes. The data indicates substantial variation across all variables, especially GDP, Trade, and Government Expenditure, highlighting large discrepancies among ASEAN countries over the study period. The skewness and kurtosis values indicate that the majority of variables deviate from normal distribution, exhibiting large tails and a degree of positive skewness, particularly in variables such as GDP and government expenditure, which may signify the presence of outliers or rapidly growing economies.

The dependent variable, CO2 emissions, has moderate variability and a slight right skew, indicating that while the majority of countries have comparatively low emissions, a minority possess substantially higher levels. The considerable variation in values across all categories underscores the heterogeneity in economic, environmental, and demographic conditions among ASEAN members. The discrepancies need the application of panel data analysis, enabling the examination to account for country-specific effects and temporal dynamics in evaluating the correlation between GDP and carbon emissions.

Table 2. Summary Statistic

Variable	Mean	Variance	Std. Dev	Skewness	Kurtosis	Min	Max
CO2	32.08932592	1445.032852	38.01358773	1.686178338	3.03442791	0.14	198.9310193
GDP	$1.94377e^{11}$	$4.4559e^{22}$	$2.1109e^{11}$	1.83532703	4.424375703	2736044527	$1.12227e^{12}$
TR	131.5501108	7466.685566	86.40998534	1.835255161	2.613722831	35.84720848	437.3267149
EF	94407343.58	$1.06756e^{16}$	103322729.4	1.572262512	2.312492041	980476.2	462464035.5
NRR	9.590474973	106.3023294	10.3103021	1.095618236	0.059605517	0.000169266	38.94423345
POP	58011080.29	$5.08887e^{15}$	713363000	1.635780495	1.975410604	255292	278830529
GOV	$1.31813e^{11}$	$2.05784e^{22}$	$1.43452e^{11}$	1.731038487	3.655681774	2596941643	$7.23475e^{11}$

Source: author's work based various sources

From the plot of relationship of LnCO2 and GDP (LnGDP), we see that there is a clear positive relationship between GDP and carbon dioxide emissions: as GDP increases, carbon dioxide emissions also rise. This catchment illustrates what economists call the environmental tradeoff in economic expansion: a large chunk of carbon emissions is produced in the name of industrial activity and modern-day energy use. Similarly, Trade Openness (LnTR) is also positively associated with LnCO2 showing that, the more open a country with trade the higher emissions through more economic activities will be. Ecological footprint (LnEF) and LnCO2 also show a strong positive relationship, indicating that the larger a country's ecological footprint, the higher its carbon dioxide emissions, reflecting environmental pressures due to economic activity and resource consumption.

Natural Resources Rent (NRR) also has a relationship with LnCO2 although it is not very strong, indicating that natural resource utilisation contributes to carbon emissions, but is not the main factor determining the level of emissions. Population (LnPOP) shows a strong positive correlation with LnCO2, indicating that an increase in population tends to push up carbon emissions due to increased energy demand and economic activity. Finally, Government expenditure (LnGOV) also shows a strong relationship with LnCO2, indicating that an increase in government spending, especially on infrastructure development and productive sectors, tends to increase economic activity that contributes to carbon emissions.

Overall, these relationships highlight the complexity of managing economic growth and environmental sustainability in ASEAN countries. However, it is too early to draw conclusions based solely on the scatter plot, and further inferential approaches are needed to gain a deeper understanding.

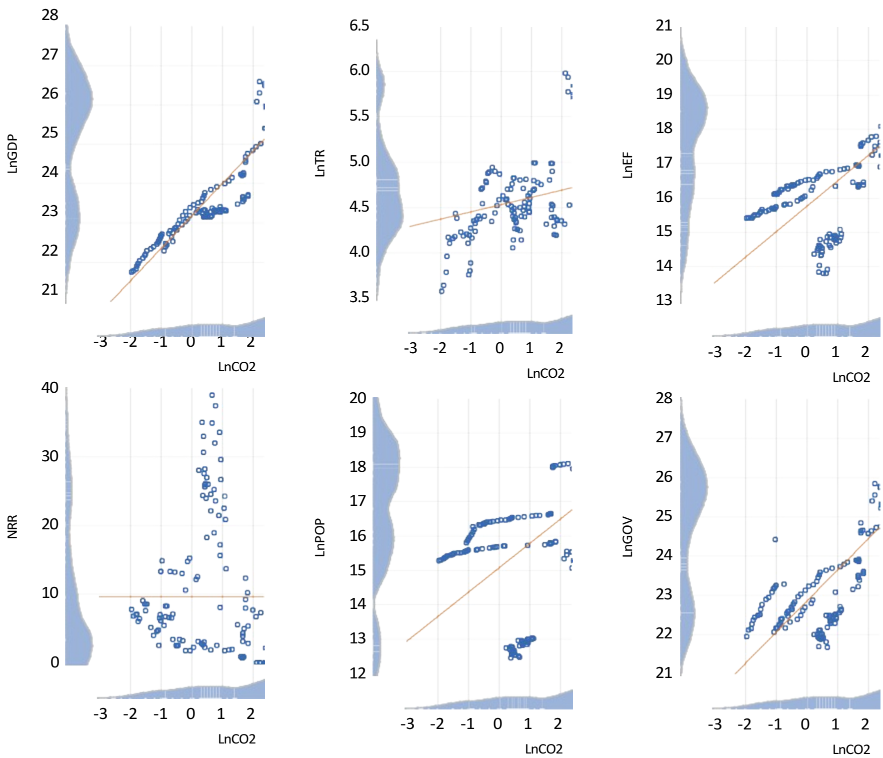

Fig. 1. Scatter Plots for Independent and Control Variables Towards Dependent Variables

The proper method of testing was determined by means of the a Cross-Sectional Dependence (CD) test prior to running any stationarity checks. As can be seen from Table 2, all of the variables show significant CD at the 1% level except NRR which has a significance of 5%. This suggests cross-sectional dependence and thus justifies use Lihe Breitung unit root test.

The stationarity tests presented in Table 3 show that all variables are non-stationary in the level form and with no trend. However, when taking first differences on all variables, only P-values greater than 0.0 satisfy both conditions.

To validate these findings, the Fisher-ADF test was also conducted (Table 4), yielding results consistent with the Breitung test—where all variables achieved stationarity at the first difference. Therefore, all variables are integrated of order one, I(1), confirming the suitability of the panel ARDL approach and the need for subsequent cointegration testing.

Table 3. Pesaran CD Test

Variable	CD-Test	P-Value	corr	abs(corr)
LnCO2	17.99	0.0000	0.917	0.527
LnGDP	7.88	0.0000	0.603	0.652

LnTR	11.17	0.0000	0.226	0.462
LnEF	9.71	0.0000	0.260	0.226
NRR	1.74	0.05	0.083	0.167
LnPOP	21.47	0.0000	0.897	0.897
LnGOV	6.14	0.0000	0.115	0.283

Source: author's work based various sources

Table 4. Breitung Unit Root Test

Variable	Lag Zero	Lag Zero with Intercept & Trend	Lag One	Lag One with Intercept &Trend	First Difference
LnCO2	1.667	1.53028	1.268	1.34195	-4.29810***
LnGDP	-0.903	2.73474	1.209	168653	-1.80280**
LnTR	1.193	0.86630	2.002	-0.31620	-2.16352**
LnEF	-1.335	-1.28108	-1.840	-0.99531	-5.82627***
NRR	1.536	-1.00167	-1.273	-1.29484	-2.38263**
LnPOP	1.825	18.9807	0.729	6.20629	-2.05671**
LnGOV	1.458	0.06950	1.365	0.09322	-4.12241***

*** p<0.01, ** p<0.05, * p<0.1
Source: author's work based various sources

Table 5. Fisher ADF Unit Root Test

Variable	Lag Zero	Lag Zero with Intercept & Trend	Lag One	Lag One with Intercept &Trend	First Differen ce
LnCO2	0.04482	-1.98997	-0.37996	-2.81097***	-7.94277***
LnGDP	0.54747	1.05159	0.97389	-0.64681	-6.52386***
LnTR	-0.54148	0.31118	-0.71348	-0.55205	-6.69360***
LnEF	0.93123	-2.00690**	0.66911	-1.92692	-8.74674***
NRR	-2.71183***	-1.62766	-3.02571***	-2.00605**	-2.90029***
LnPOP	0.87525	1.36668	1.51599	-3.78715***	-12.0292***
LnGOV	2.31137	-2.97552***	3.24749	-3.44352***	-8.62318***

*** p<0.01, ** p<0.05, * p<0.1
Source: author's work based various sources

The following step evaluate cointegration by means of Pedroni ARDL approach to investigate the romantic relationship either our carbon emission along with other features. We used the framework of Pedroni, Kao and Fisher, with a p-value threshold of
0.1 (so not very high in today's standards), conclusions about some kind of cointegration between variables. The results from the Pedroni test on the presence of cointegration among the variables in the model are illustrated in table 6, where the null hypothesis state the absence of cointegration among the variables and the alternative stating that there is at least one long-run equilibrium relationship among the variables. Results indicate that both the Phillips-Perron and augmented-Dickey-Fuller statistics are lower than the p -value of 0.01. Additionally, MPP is not important, while existence of cointegration is. However withtwo such extremely high values we reject the null hypothesisand conclude that there is a significant long run cointegratingrelationship between these variables.

Table 6. Pedroni Cointegration Test

Test	Statistics	p-value	Conclusion
Modified Phillips-Perron t	1.862	0.103	No Long-Run Cointegration
Phillips-Perron t	4.715	0.000	Long-Run Cointegration
Augmented Dickey-Fuller t	3.908	0.000	Long-Run Cointegration

Source: author's work based various sources

Based on the Panel ARDL estimation results in Table 5, which compares the Dynamic Fixed Effect (DFE), Pooled Mean Group (PMG), and Mean Group (MG) approaches, the influence of variables on carbon emissions (CO_2) shows notable differences between the short and long run. Overall, most variables have stronger and more significant long-run effects, implying that policy and structural changes require time to impact environmental outcomes.

In the long run, economic growth has a positive and significant effect on CO_2 emissions in all three models—strongest in the PMG—supporting the early stage of the Environmental Kuznets Curve hypothesis. Conversely, trade openness significantly reduces emissions, possibly due to cleaner technology adoption and higher production efficiency. The ecological footprint increases emissions significantly, confirming that greater ecological pressure leads to higher CO_2 levels.

Natural resource rent (NRR) and government expenditure show negative and significant long-run effects, suggesting more sustainable resource management and effective government interventions. Meanwhile, population remains insignificant, indicating that emission levels depend more on productivity and energy intensity than on population size alone.

In the short run, only economic growth (PMG and MG) and trade show consistent significance, implying that short-term economic and trade activities tend to raise emissions, while other variables display unstable short-term effects.

Finally, the Hausman test was conducted to assess the reliability of the DFE, PMG, and MG models. This test helps determine the most appropriate estimator—PMG or MG—based on whether long-run coefficients are assumed homogeneous or heterogeneous across units.

Table 7. Panel ARDL Estimation Results

Variables	DFE		PMG		MG	
	LR	SR	LR	SR	LR	SR
D(LnGDP)		0.314582		0.279299*		0.74131*
D(LnTR)		0.442042		-0.147459**		0.12783*
D(LnEF)		0.073613		0.138391		0.089213
D(NRR)		0.0924109		0.251737		0.148510
D(LnGOV)		0.1753053		0.077619		0.092713
D(LnPOP)		0.0873501		0.116504		0.077146

LnGDP	0.41872*	0.313880***	0.11347***
LnTR	-0.09242*	1.522441***	0.93414**
LnEF	0.381905**	2.968266***	1.47194***
NRR	-0.01848***	0.083447***	-0.16314**
LnGOV	0.047141*	0.723367***	0.24913**
LnPOP	0.163235	0.339253	0.4910142
Constant	-0.91474	4.65088**	6.09244***

*** p<0.01, ** p<0.05, * p<0.1; LR: Long-Run; SR: Short-Run
Source: author's work based various sources

The Hausman test results displayed in Table 6 show that in two out of three tests (possibly for each main variable or partial model), the PMG model is better as there is no significant difference with the MG model. This means that the assumption of longrun coefficient homogeneity in PMG is acceptable and efficient to use. In other words, PMG is considered capable of capturing the dynamics of long-run relationships between variables more appropriately in the context of the ASEAN panel.

Based on these results, this study then chose to use the PMG model in further analysis. This is based on the consideration that PMG is able to accommodate short-run heterogeneity among ASEAN countries, but still assumes that the long-run relationship between variables is uniform (homogeneous). This approach provides a balance between the flexibility of the MG model and the efficiency of the DFE model, making it the most suitable to explain the relationship between financial development and carbon emissions in the ASEAN region.

Table 8. Hausman Test Result

	Prob $> \chi^2$	**Decision**
PMG – MG	0.4183	PMG is Preferred
DFE – PMG	0.5649	PMG is Preferred
DFE MG	0.0003	MG is Preferred

Source: author's work based various sources

5 Discussion

This study aims to examine the relationship between economic growth and carbon emission in ASEAN by employing a panel ARDL approach. Considering nine ASEAN countries over the period 1990–2022, this study aims to expose the short and long-run interactions between economic growth, and only CO2 emissions associated to energy consumption (excludes residential uses). And, it also propose international trade, ecological footprint, natural resource rent, government expenditure and population as a control variables for the analysis. Overall, results show that growth positively contributes to the long-term growth of carbon emissions, in line with the early story of Environmental Kuznets Curve (EKC).

The findings reinforce the argument that in the early stages of economic development, increased production and consumption activities tend to result in higher carbon emissions. This reflects that the economic structure of ASEAN countries still relies heavily on fossil energy-intensive sectors. Nonetheless, this result also confirms that policy interventions to steer growth in a greener and more sustainable direction are crucial to curb future emission spikes. Interestingly, the trade variable shows a negative and significant relationship with carbon emissions in the long run. This indicates that trade openness in ASEAN countries may encourage the shift to cleaner technologies or promote higher production efficiency. In other words, international economic integration seems to be a potential channel to strengthen the transition towards sustainable development in the region.

Moreover, the finding that ecological footprint contributes positively to emissions suggests that pressure on natural resources is directly proportional to the increase in carbon emissions. This result sends a strong message that development that does not take ecosystem capacity into account will exacerbate environmental degradation. On the other hand, natural resource rent and government spending show a significant negative relationship with carbon emissions in the long run. This is quite interesting as it indicates that the sustainable utilisation of natural resources and the active role of the government in allocating budgets to green sectors can reduce the rate of carbon emissions.

The absence of a significant effect of the population variable on emissions in the long run is also an important finding. This implies that population growth is not the only major factor driving carbon emissions, but is more determined by how the energy consumption patterns and economic productivity of the population are directed. Therefore, emission control policies should not only focus on demographics, but also on energy efficiency and transition to renewable energy.

In the short term, the effects of the variables analysed tend to be more volatile and inconsistent, except for the trade and economic growth variables which remain significant in some model approaches. This indicates that structural impacts on emissions take time to build up and tend not to be immediately reflected in short-term dynamics, making long-term policy interventions, such as energy reform and low-carbon development planning, more relevant for sustainable implementation.

Overall, the results of this study show that economic growth does contribute to rising carbon emissions in ASEAN, but this relationship does not exist in a vacuum. Factors such as trade openness, government spending, and ecological consumption patterns play an important role in mediating the impact. Therefore, if ASEAN wants to maintain its economic growth rate while reducing its carbon footprint, it needs adaptive, proenvironmental economic policies based on regional collaboration.

6 Conclusion

This study examines the impact of economic growth on carbon emissions in the ASEAN region using the Panel ARDL approach involving nine countries over the period 1990 to 2022. The analysis shows that economic growth has a positive and significant impact on carbon emissions in the long run, indicating that increased economic activity still tends to increase the environmental burden. This finding confirms the initial phase of the Environmental Kuznets Curve (EKC) where economic growth has not been accompanied by emission reductions.

However, the results also show the important role of other variables such as international trade, ecological footprint, natural resource rent, government spending, and population. In the long run, trade and government spending show a negative and significant relationship with emissions, signalling that open policies and government intervention can be important tools in emissions control. Meanwhile, ecological footprint contributes positively to emissions, and population shows no significant relationship, providing a new perspective to the formulation of environmental and sustainable development policies in ASEAN.

Based on the results of this study, it is important for ASEAN countries to start integrating economic and environmental policies more thoroughly into national development agendas. Increased economic growth should be directed towards not only creating economic value-added, but also minimising environmental pressures through the adoption of low-carbon technologies and more efficient production practices. Governments in each ASEAN country can play an active role by creating fiscal incentives for green sectors, and prioritising investments in renewable energy and sustainable infrastructure.

International trade has been shown to have a positive effect on reducing emissions in the long run. Therefore, ASEAN needs to strengthen regional and global co-operation in accessing green technologies and facilitating knowledge exchange across countries. This can be achieved through trade agreements that include environmental sustainability clauses, and supporting local companies to upgrade their production standards to match the increasingly stringent global demands on environmental sustainability.

Effective government spending on the environmental sector is also key. Budget allocations directed towards climate change mitigation, sustainable natural resource management, and public education on responsible consumption will strengthen the government's position as a key driver of the green transition. The government needs to develop a transparent and accountable monitoring and evaluation system to ensure the effectiveness of these programmes in the long run.

In addition, although population has not been shown to be statistically significant in the long run, policy approaches still need to consider demographic aspects thoroughly. High population growth without strengthening the quality of human resources can still increase the potential for environmental damage through inefficient energy consumption. Therefore, education, access to clean energy, and productivity enhancement should be an integral part of low-carbon development strategies in the ASEAN region.

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