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NON-LINEAR IMPACT OF ENERGY CONSUMPTION ON CO_2 EMISSIONS IN ASEAN-5 COUNTRIES

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Abstract

Using the panel autoregressive distributed lag/pooled mean group estimator (ARDL/PMG) and non-linear autoregressive distributed lag (NARDL) approaches, this study seeks to examine the linear and non-linear impact of energy consumption on CO_2 emissions for the panel of ASEAN-5 countries (Indonesia, Malaysia, Thailand, the Philippines, and Singapore) over a period of 31 years (1990-2020). The empirical research revealed that all the explanatory variables, including energy consumption, have a negative impact on ASEAN-5's CO_2 emissions in the long-run. In the short-run relationship, energy consumption has a statistically significant effect on CO_2 emissions in the ASEAN-5, whereas the other explanatory factors have statistically insignificant effects. In addition, empirical results indicate that positive shocks of energy consumption reduce CO_2 emissions, whereas negative shocks to energy consumption contribute to an increase in CO_2 emissions in ASEAN-5 countries, indicating that the sources of energy move towards renewable energy sources in the long-run. In the short-run, the positive shock of energy consumption caused environmental damage, although the other variables suggest minor effects. This is because the ASEAN-5 tends to rely on fossil fuels to create energy in the short-run, resulting in an increase in CO_2 emissions. To improve energy efficiency, however, policymakers should impose appropriate policies and investment programs. The policymakers should also stimulate research and investment to enhance the generation of renewable energy sources. Lastly, ASEAN-5 should dedicate greater resources to the development of green technology.

Keywords: CO_2 Emissions, Energy Consumption, Non-Linear Analysis, ARDL/PMG Approach, NARDL Approach.

JEL codes: H23, K32, O13, O44, P28, Q56

INTRODUCTION

Climate change and global warming are instances of anthropogenic catastrophes that jeopardize the biodiversity of the Earth. The prominent global consequences of climate change include alterations in weather patterns and the escalation of sea levels. These changes pose a threat to food production and heighten the probability of catastrophic floods. The United Nations has acknowledged the significance of these exceptional events (UN, 2021). Bekun et al. (2019) argue that the principal factor behind climate change is the rising concentrations of carbon dioxide (CO_2) present in the atmosphere. BP's analysis reveals that the rise in CO_2 emissions in 2021 can be attributed to increased energy consumption, industrial operations, flaring, and methane emissions (measured in terms of carbon dioxide equivalent), collectively accounting for a 5.7% increase. Specifically, there was a 5.9% increase in carbon dioxide emissions, reaching the same levels as in 2019. The study reported a marginal rise of 2.9% in CO_2 emissions resulting from flaring, but emissions from methane and industrial activities exhibited a 4.6% increase. The primary driver behind the increase in CO_2 emissions is the substantial energy consumption, predominantly derived from fossil fuels such as coal, oil, and gas. The

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majority of greenhouse gas emissions, accounting for almost three quarters, and about ninety percent of carbon dioxide emissions are derived from fossil fuels, establishing them as the primary catalyst for climate change (UN, 2021). The release of CO_2 emissions creates a barrier that captures solar heat, leading to climate change and global warming. The phenomenon of global warming is currently experiencing unprecedented acceleration on our planet. This phenomenon is causing several hazards to both humans and the environment, as it alters weather patterns and disrupts the natural equilibrium.

The ASEAN-5 nations, part of the Association of Southeast Asian Nations, face considerable vulnerability to the effects of global warming. As per the analysis in the 5th ASEAN Energy Outlook, there is an expected threefold increase in energy consumption by 2040. This represents a growth rate that is twice as high as the global average, almost 4% every year. Presently, electricity constitutes 18% of the overall energy consumption. Nevertheless, it is projected to undergo substantial expansion and attain a 26% share by 2040, aligning with the global average (EIA, 2019). The coal consumption in the ASEAN region is now seeing the highest growth rate globally in terms of energy demand. The energy output in the ASEAN area is predominantly contributed by four nations, namely Indonesia, Malaysia, Thailand, and the Philippines, which collectively account for over 90% of the total energy production (Suryadi, 2020). Out of the total installed capacity of 235.4 GW in ASEAN in 2017, more than 68.1% was derived from gas and coal sources. Nevertheless, hydrogen secured the third position in terms of installed capacity, amounting to 46 GW (ASEAN Focus, 2019).

The energy sector within the ASEAN-5 nations has emerged as the primary driver of climate change and the consequential surge in carbon dioxide emissions, thereby presenting formidable challenges for the well-being of humanity. Multiple research studies underscore the correlation between the escalation of CO_2 emissions and the consequential environmental deterioration, with energy consumption playing a pivotal role (Munir et al., 2019; Vo et al., 2019; Alharthi et al., 2021; Salari et al., 2021). The ASEAN-5 countries find themselves particularly susceptible to the escalating levels of CO_2 emissions, a situation that not only heightens the perils of climate change but also exacerbates global warming, thereby adversely affecting the economic and societal progress of nations. Indonesia, the Philippines, and Malaysia have borne the brunt of climate-induced disasters, experiencing the most pronounced human and economic tolls (Ding & Beh, 2022).

Furthermore, in light of the abundant recent research exploring the nexus between energy consumption and CO_2 emissions (for instance, Zhu et al. (2016), Munir et al. (2019), Vo et al. (2019), Munir & Riaz (2019)), the primary aim is to elucidate the intricacies of this relationship. It is crucial to tailor policy frameworks to accommodate the curvilinear correlation between these variables, in contrast to the linear correlation emphasized by Chunyu et al. (2021). Previous studies have predominantly focused on the linear connection between energy consumption and environmental impact, often neglecting the repercussions of CO_2 emissions on ecosystems when energy usage surpasses a specific threshold. This critical aspect is frequently overlooked in research endeavors. The ASEAN-5 member states consistently exhibit the highest energy demand compared to other nations in the group. Policy formulations

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have traditionally been constrained by data illustrating a linear trend. However, a more comprehensive understanding of the interplay between energy usage and CO_2 emissions can be attained by approaching the analysis from a non-linear perspective. Further investigation is imperative to delve into the non-linear correlation between energy consumption and CO_2 emissions.

A principal objective of this investigation is to bridge a void in the prevailing literature by scrutinizing the interconnection between energy consumption and CO_2 emissions in the ASEAN member states. Furthermore, the research endeavors to unveil potential non-linear associations between energy consumption and CO_2emissions within the specified ASEAN nations. The study posits two pivotal research inquiries: (1) What repercussions does energy utilization have on both current and future CO_2 emissions? (2) Is there evidence of a non-linear correlation between energy consumption and CO_2 emissions? This research aspires to yield substantive contributions to academic understanding and the formulation of policies, with a particular emphasis on benefiting the ASEAN-5 nations where a notable dearth of literature on energy and the environment persists. The outcomes are anticipated to illuminate a more lucid correlation between energy consumption and CO_2 emissions, holding intrinsic significance. Moreover, the study rectifies the existing knowledge gap by probing into the non-linear relationship between energy consumption and carbon dioxide emissions in the ASEAN-5 countries. Consequently, policymakers in these nations will be equipped with updated information to reassess energy-environment policies, taking into account both the non-linear impacts of energy consumption and its linear consequences.

This study investigates the non-linear relationship between energy consumption and CO_2 emissions in five distinct sections. The first section of the introduction presents indicators, study subjects, objectives, concerns, and the contributions of the studies. Subsequently, the literature review explores prior investigations about the correlation between energy use and CO_2 emissions, ultimately uncovering a deficiency in the existing knowledge base. The sections titled "Data Description, Model Specification, and Methodology" provide a detailed explanation of the variables, data, model specifications, and methodology employed in this research study. Furthermore, the results and comments section use economic reasoning and references to prior research in order to analyse and elucidate the findings. In conclusion, the final component of the research encompasses a concise summary and the potential ramifications for policy.

LITERATURE REVIEW

The upswing in energy consumption within developing nations serves as a catalyst for the escalation of carbon dioxide levels, precipitating adverse environmental repercussions. A study conducted by Liu et al. (2019) spanning the period from 1980 to 2016 uncovered a direct correlation between energy utilization and CO_2 emissions. A thorough investigation in Pakistan delved into the intricate interrelations among carbon dioxide emissions, energy consumption, GDP growth, and foreign tourist receipts. Employing Granger causality, autoregressive distributed lag (ARDL), and dynamic ordinary least squares (DOLS) models for short- and

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long-term predictions, the research found that revenue generated from tourism did not wield a significant influence on CO_2 emissions. Conversely, the primary instigators were identified as the escalating levels of energy consumption and economic activity. Granger causality data corroborated unidirectional relationships between energy use, GDP, and CO_2 emissions, with tourism exhibiting no discernible impact on carbon dioxide emissions. A study by Ahmend et al. (2020) highlighted a positive correlation between energy consumption and economic growth, as well as a direct association between energy consumption and CO_2 emissions. Similarly, Khan et al. (2020) observed a favorable correlation between energy consumption, economic growth, and CO_2 emissions in Pakistan from 1965 to 2015, both in the short and long term.

This research adopts a national perspective, building upon the groundwork laid by Munir and Riaz (2019), who delved into the dynamics among rising energy consumption, GDP, and carbon dioxide emissions. Concentrating on Bangladesh, India, and Pakistan during the period from 1985 to 2017, the researchers identified a non-linear correlation between energy consumption and CO_2 emissions. Specifically, heightened use of gas, electricity, and coal was linked to an upward trajectory in CO_2 emissions, while reduced consumption of coal and electricity led to sustained lower emissions. The relationships between Pakistan's electricity consumption and CO_2 emissions, as well as between Bangladesh and Pakistan's coal consumption and CO_2 emissions, displayed non-linear patterns with immediate fluctuations in specific countries' emissions. In a comprehensive analysis spanning 2001 to 2019, Muhammad (2019) explored the connections among energy consumption, CO_2 emissions, and economic growth, utilizing panel data from 68 countries. The data revealed a significant increase in energy consumption, coupled with accelerated economic growth in both developed and developing nations. Carbon dioxide emissions also increased concomitantly with heightened energy consumption across all countries. Notably, developed and MENA countries exhibited a decline in energy consumption and CO_2 emissions, while emerging economies displayed the opposite trend, possibly attributable to their expanding economies characterized by increased energy consumption and decreased CO_2 emissions. To scrutinize the relationships between energy consumption, CO_2 emissions, tourism, and GDP in South Asian nations, Selvanathan et al. (2020) analyzed these variables from 1990 to 2014. The research findings revealed that tourism contributed to an increase in GDP.

Chontanawat's (2020) investigation employed cointegration and causality models to explore the dynamic relationship among energy consumption, CO_2 emissions, and economic production in ASEAN from 1971 to 2015. The analysis unveiled a reciprocal cause-and-effect connection between power consumption and CO_2 emissions. Notably, power consumption demonstrated a direct and immediate impact on the release of CO_2 into the atmosphere. This implies that a reduction in energy consumption over time could lead to lower levels of CO_2 emissions, while an increase in energy consumption is likely to result in higher CO_2 emissions. In the study by Gillani and Sultana (2020), the Environmental Kuznets Curve (EKC) framework was explored using data from nine ASEAN countries spanning 1970 to 2019. The panel ARDL/PMG approach, employed for both short- and long-term estimations, revealed a 0.8377% increase in CO_2 emissions for every 1% rise in energy use. CO_2 emissions exhibited

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a positive correlation with economic growth, increasing by 2.05% for every 1% rise in economic growth. However, a negative correlation was observed with the square gain in economic growth, decreasing by 0.1622% for every unit increase in the square gain. These results align with the Environmental Kuznets Curve (EKC) theory. Batool et al.'s (2021) study, covering the period from 1980 to 2018, analyzed the interrelationships among economic growth, energy consumption, urbanization, and environmental quality in the ASEAN-5 nations. The Granger causality test results supported the study's conclusions, indicating a correlation between energy usage and the urban population in ASEAN-5 countries.

RESEARCH METHODOLOGY

Data Description

The study focuses on secondary sources to gather data in order to achieve its objectives. The ASEAN-5 data collection includes measurements of carbon dioxide emissions, energy consumption, and control variables such as GDP growth, trade, and urbanization. This data set is updated annually. The Global Carbon Atlas provides data sets on carbon dioxide emissions, Our World in Data offers information on energy consumption, and the World Development Indicator (WDI) accounts for economic growth, trade, and urbanization. The dataset comprises 31 observations, spanning from 1990 to 2020, sourced from publicly accessible data. TABLE 1 presents the measurement and explanation of each variable, as reported by the World Bank, Our World in Data, and the Carbon Atlas.

Table 1: Description of variables

Variable	Unit	Description
CO_2	$MtCO_2$	Carbon dioxide is emitted through the combustion of fossil fuels, encompassing solid, liquid, and gaseous fuels, along with the process of gas flaring.
EC	kWh	Per capita fossil fuel consumption denotes the average energy usage of coal, oil, and gas per person.
EG	Constant 2010 US dollar	The aggregate gross value added by resident producers within the economy, encompassing product taxes but excluding subsidies in the value of items.
TR	% of GDP	Trade pertains to the comprehensive worth of goods and services that a nation both exports and imports, quantified as a proportion of its Gross Domestic Product (GDP).
UR	% of annual	The urban populace, as identified by official national statistical bodies.

Based on several prior investigations (Souza et al., 2018; Banday & Aneja, 2019; Munir et al., 2019; Anwar et al., 2020; Radmehr et al., 2021). The rationale behind selecting economic growth as the control variable is as follows. Currently, numerous emerging nations are confronting significant economic challenges. Consequently, these emerging countries are increasing their energy consumption in order to stimulate economic growth and improve the production of goods and services. Consequently, the efforts to address these difficulties by ramping up production and promoting economic growth have the unintended consequence of exacerbating environmental degradation, contributing to global warming, and depleting natural resources (Anwar et al., 2020).

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According to the International Energy Agency (IEA, 2017), urbanization is accountable for around 70% of energy-related CO_2 emissions on a global scale. In 2021, ASEAN was inhabited by more than 700 million individuals (Nathaniel & Khan, 2020). Wang et al. (2016) have observed a significant increase in urbanization throughout the states in this area. Urbanization has a substantial influence on the carbon dioxide (CO_2) emissions of both developed and developing nations, as stated by Ali et al. (2019). The substantial impact of urbanization on CO_2 emissions warrants its incorporation as a control variable.

Research conducted by Dogan & Seker (2016) and Nathaniel & Khan (2020) demonstrates a significant correlation between commerce and CO_2 emissions, therefore justifying its use as a control variable. The heightened trade among ASEAN nations has yielded numerous advantages, particularly in the domains of global trade, overseas investments, and technological advancements. According to Nathaniel & Khan (2020), the primary factor contributing to the exacerbation of environmental deterioration by increased trade is the rise in CO_2 emissions. ASEAN's involvement in trade operations has been shown to have a detrimental effect on environmental quality. Hence, within the framework of ASEAN-5, it is imperative to incorporate commerce as the decisive element in assessing CO_2 emissions.

Model Specification

According to Libobikiene and Butkus (2018), the researchers do not hold the belief that economic improvement will lead to a decrease in CO_2 emissions. Due to their ongoing extensive use, fossil fuels persist as the primary contributors to carbon dioxide emissions, which in turn exhibit a positive correlation with economic expansion. The taxonomy for variables and effects proposed by Grossman and Kruger (1991) consists of three components: scale, approach, and composition. The extent of environmental harm is intensified by the cumulative influence, involving elements such as the usage of fossil fuels and other variables. The composition effect occurs when the economic structure undergoes a transformation as cleaner industries, such as renewable energy, surpass more polluting ones. The utilization of state-of-the-art technology additionally enhances the efficacy of the technique, hence facilitating the emergence of the Environmental Kuznets Curve (EKC) and reducing CO_2 emissions. This research introduces a framework that assesses the impact of energy consumption, economic growth, trade, and urbanization on CO_2 emissions in the ASEAN-5 nations. The model is formulated in both functional equation 1 and equation 2 forms. The data was transformed using logarithmic conversion in order to standardize the measurement units.

$$LCO2 = f(LEC, LEG, LTR, LUR) \quad (1)$$

$$LCO2_{it} = \beta_0 + \beta_1 LEC + \beta_2 LEG + \beta_3 LTR + \beta_4 LUR + \mu_{it} \quad (2)$$

The variables in question are LCO2 (representing the logarithm of CO_2 emissions), LEC (representing the logarithm of energy consumption), LEG (representing the logarithm of economic growth), LTR (representing the logarithm of trade), and LUR (representing the logarithm of urbanization). β_0 represents the intercept, while β_1, β_2, β_3, and β_4 denote the coefficients associated with the estimated parameters.

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METHODOLOGY

Pooled Mean Group (PMG) Estimator

The PMG estimator cleverly combines the techniques of pooling and averaging, employing them as unique strategies. While the estimator mandates consistency in long-term coefficients, it allows for unrestrained diversity in intercepts, short-term coefficients, and error variances across different groups. Considering this scenario, a reasonable inference is that every group will exhibit steadfast and lasting connections between variables over time. By maximizing the provided equation, the optimization process focuses on achieving the maximum likelihood (ML), yielding estimates for both the long-run coefficient and group-specific error-correction coefficients.

$$\ell_T(\gamma) = -\frac{T}{2}\sum_{i=1}^{N} ln2\pi\sigma_i^2 - \frac{1}{2}\sum_{i=1}^{N}\frac{1}{\sigma_1^2}(\Delta y_i - \phi_i\xi_i(\theta))'H_i(\Delta\gamma_i - \phi_i\xi_i(\theta)) \quad (3)$$

where, $H_i = I_T - W_i\left(W_i'^{W_i}\right)^{-1}W_i', I_T$ pertains to a T-dimensional identity matrix, and $\gamma = (\theta', \phi', \sigma')'$.

The equation outlined earlier undergoes assessment through the t PMG estimator. The objective of the study is to scrutinize the long-term coefficient without presuming uniform dynamics in male or female interest. It facilitates the exploration of enduring similarities without imposing consistency in short-term parameters. The inherent outcomes of employing the PMG selection entail the scrutiny of parameters over an extended duration and the computation of average estimates across a shorter timeframe.

Panel Non-Linear Auto-Regressive Distributed Lag (NARDL) Test

This study endeavors to evaluate the precision of the non-linear correlation between energy consumption and CO_2 emissions. To accomplish this, the study will utilize the panel non-linear auto-regressive distributed lag (NARDL) test to discern the non-linear cointegration connection between positive and negative shocks related to energy-growth-environment variables across various temporal spans, encompassing both shorter and longer durations. The NARDL test, as introduced by Shin et al. (2014), builds upon the linear ARDL model established by Pesaran and Shin (1999) and Pesaran et al. (2001). Shin et al. (2014) incorporated the methodologies of Granger and Yoon (2002) and Schorderet (2003) in their work to decompose stationary variables into positive and negative fluctuations. As a result, the variable X and its two components, forming a partial sum of variables, are represented as follows:

$$X^+ = \sum_{j=1}^{t}\Delta X_j^+ = \sum_{j=1}^{t} max(\Delta X_j, 0) \quad (4)$$

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$$X^- = \sum_{j=1}^{t} \Delta X_j^- = \sum_{j=1}^{t} min(\Delta X_j, 0) \quad (5)$$

The enduring association between Y and X within a non-linear framework will be illustrated as follows:

$$Y_t = \beta^+ X_t^+ + \beta^- X_t^- + \mu_t \quad (6)$$

$$X_t = X_0 + X_t^+ + X_t^- \quad (7)$$

where, β^+ and β^- represent the long-run parameters, while X^+ and X^- denote the scalars of the decomposition partial sums.

In line with the approach elucidated by Shin et al. (2014), the formulation of the partial asymmetry cointegration equation involves the integration of positive and negative shocks of the explanatory variable into the standard symmetric equation. The framework of the NARDL model is outlined as follows:

$$\begin{aligned} \Delta LCO2_{t,i} = {} & \alpha_0 + \sum_{i=1}^{n} \mu_1 \Delta LCO2_{t-i} + \sum_{i=0}^{m} \mu_2^+ \Delta LPOS(REC)_{t-i} + \sum_{i=0}^{m} \mu_2^- \Delta LNEG(REC)_{t-i} \\ & + \sum_{i=0}^{k} \mu_3^+ \Delta LPOS(NREC)_{t-i} + \sum_{i=0}^{k} \mu_3^- \Delta LNEG(NREC)_{t-i} \\ & + \sum_{i=0}^{r} \mu_4^+ \Delta LPOS(GDP)_{t-i} + \sum_{i=0}^{r} \mu_4^- \Delta LNEG(GDP)_{t-i} + \gamma_0 LCO2_{t-1} \\ & + \gamma_1^+ LPOS(REC)_{t-1} + \gamma_1^- LNEG(REC)_{t-1} + \gamma_2^+ LPOS(NREC)_{t-1} \\ & + \gamma_2^- LNEG(NREC)_{t-1} + \gamma_3^+ LPOS(GDP)_{t-1} + \gamma_3^- LNEG(GDP)_{t-1} + \omega_t \end{aligned} \quad (8)$$

In equation (8), the variables m, n, r, and k represent the optimal predicted lag duration for the model. To evaluate the long-run asymmetric effects of the dependent variable and explanatory variables, the Standard Wald test will be employed. The test will examine the following null and alternative hypotheses:

$$H_0: (\gamma_1^+ = \gamma_1^-); (\gamma_2^+ = \gamma_2^-)$$
$$H_1: (\gamma_1^+ \neq \gamma_1^-); (\gamma_2^+ \neq \gamma_2^-)$$

Dismissing the null hypothesis confirms the presence of asymmetrical effects from both renewable and non-renewable energy use, as well as economic growth, on CO_2 emissions in the long term. The computation of the long-run elasticity can be accomplished using the following formula: $LNREC^+ = \frac{-\gamma_1^+}{\gamma_0}, LNREC^- = \frac{-\gamma_1^-}{\gamma_0}, LREC^+ = \frac{-\gamma_2^+}{\gamma_0}, LREC^- = \frac{-\gamma_2^-}{\gamma_0}, LGDP^+ = \frac{-\gamma_3^+}{\gamma_0}, LGDP^- = \frac{-\gamma_3^-}{\gamma_0}$.

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The present study will integrate the methodologies of panel NARDL and panel ARDL, as proposed by Shin et al. (2014) and Pesaran et al. (1999), respectively. However, the panel NARDL model will be specifically employed to achieve the objectives of this study. The selection of the NARDL strategy for this investigation is grounded in three distinct advantages over alternative approaches. Firstly, it possesses the capability to quantify the non-linear asymmetries present in the data. Additionally, it facilitates the measurement of the impact of data variability and is better suited for assessing the effects of integrating variables with mixed orders. Munir and Riaz (2019) applied the NARDL methodology to quantify the non-linear impact of energy consumption on CO_2 emissions in South Asian nations. Toumi and Toumi (2019) utilized the Nonlinear Autoregressive Distributed Lag (NARDL) model to investigate the non-linear relationship between renewable energy, CO_2 emissions, and real GDP. Similarly, Masibau et al. (2019) employed the same methodology to analyze the connection between environmental degradation, energy consumption, and economic growth.

Thus, the non-linear ARDL panel model can be represented as follows:

$$\Delta Y_{it} = \theta_i ECT_{it} + \sum_{j=1}^{p-1} \lambda_{ij}^{*} \Delta Y_{i,t-j} + \sum_{j=0}^{q-1} \left(\delta_{ij}^{*'+} \Delta X_{i,t-j}^{+} + \delta_{ij}^{*'-} \Delta X_{i,t-j}^{-} \right) + \mu_i + \varepsilon_{it} \qquad (9)$$

where the $ECT_{it} = \phi_i Y_{i,t-1} - (\beta_i^{'+} X_{i,t}^{+} + \beta_i^{'-} X_{i,t}^{-})$.

EMPIRICAL FINDINGS

Results of Panel Unit Root Test

This segment delves into exploring how energy utilization and various control factors influence CO_2 emissions. Initially, tests for unit root and cointegration are employed to identify stationarity and establish a condition of long-term equilibrium. Moving forward, the EViews software will be employed to execute the pool mean group (PMG) technique. Furthermore, we will utilize the non-linear autoregressive distributed lag (ARDL) model to evaluate the unique effects of energy consumption on CO_2 emissions within the ASEAN-5 countries.

Table 2: Panel Unit Root Test Results (ASEAN-5)

Individual Intercept						
Test Method	Levin, Lin and Chu		Im, Pesaran and Shin W-stat		PP – Fisher Chi-square	
	Level	1st Difference	Level	1st Difference	Level	1st Difference
LCO2	-4.4408*** (0.000)	-5.7896*** (0.000)	-3.0513*** (0.001)	-9.1682*** (0.000)	34.3637*** (0.000)	108.193*** (0.000)
LEC	-6.4376*** (0.000)	-4.6971*** (0.000)	-3.5381*** (0.002)	-6.4967*** (0.000)	63.9053*** (0.000)	57.0743*** (0.000)
LEG	-1.7537** (0.040)	-2.5622*** (0.005)	1.1148 (0.8675)	-4.9175*** (0.000)	7.5228 (0.675)	45.4962*** (0.000)
LTR	0.5393 (0.705)	-9.4326*** (0.000)	0.7873 (0.785)	-9.2587*** (0.000)	5.9920 (0.816)	85.4573*** (0.000)

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LUR	0.7471 (0.773)	-11.1523*** (0.000)	0.6643 (0.747)	-10.5671*** (0.000)	24.9520*** (0.005)	106.884*** (0.000)
Individual Intercept and Trend						
LCO2	-1.9541** (0.025)	-1.7460** (0.040)	-2.43555*** (0.007)	-8.5516*** (0.000)	25.4177*** (0.005)	489.006*** (0.000)
LEC	-0.83235 (0.203)	-2.7870*** (0.003)	1.0636 (0.856)	-6.8639*** (0.000)	2.3291 (0.993)	125.575*** (0.000)
LEG	-0.2792 (0.390)	-0.6006** (0.025)	-0.7325 (0.232)	-3.4456*** (0.000)	9.3956 (0.4950)	32.9461*** (0.000)
LTR	-1.0250 (0.153)	-8.3498*** (0.000)	0.6881 (0.754)	-8.7545*** (0.000)	9.7483 (0.463)	105.978*** (0.000)
LUR	1.8126 (0.965)	-9.5661*** (0.000)	0.3196 (0.625)	-9.3040*** (0.000)	22.9483** (0.011)	109.671*** (0.000)
None						
LCO2	6.3355 (1.000)	-7.6650*** (0.000)	…	…	0.76312 (1.000)	279.116*** (0.000)
LEC	4.7960 (1.000)	-7.6348*** (0.000)	…	…	0.1551 (1.000)	72.4480*** (0.000)
LEG	8.7269 (1.000)	-6.1761*** (0.000)	…	…	0.0030 (1.000)	49.5349*** (0.000)
LTR	-0.4502 (0.326)	-11.1491*** (0.000)	…	…	5.8453 (0.828)	125.307*** (0.000)
LUR	-3.8737*** (0.000)	-13.0154*** (0.000)	…	…	29.4314*** (0.001)	168.398*** (0.000)

Notes: Null hypothesis states that panel data has a unit root or is non-stationary (p-value greater than 5%). The alternative hypothesis posits that panel data has no unit root or is stationary (p-value less than 5%). Values in the brackets represent p-values. The asterisks ***, **, and * signify the significance levels at 1%, 5%, and 10%, respectively.

This empirical inquiry employs a variety of unit root tests, encompassing the Fisher-Type test, the Im, Pesaran, and Shin (2003) test, as well as the Levin, Lin, and Chu (LLC) (2002) test. Summarized in TABLE 2, these tests collectively reveal compelling evidence. The outcomes from diverse unit root tests point to the rejection of the null hypothesis for three variables: CO_2 emissions, energy consumption, and economic growth (LCO2, LEC, and LEG). This rejection is apparent given that the p-values dip below the 5% significance threshold. In line with prior research, this refutation of the null hypothesis suggests the absence of a unit root for these variables. The chi-square test underscores a noteworthy lack of mobility, signifying that a unit root exists at the level when the p-value exceeds 5%.

Essential to the analysis is the computation of the initial difference for D(LTR) and D(LUR) based on the data in Table 3. Consequently, applying the first difference results in stationarity for the LTR and LUR variables.

Moreover, the outcomes exhibit consistency across diverse techniques employed to scrutinize the presence of a unit root in the datasets. Subsequently, the examination of panel cointegration among variables will be carried out using the Pedroni Residual Cointegration test.

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Results of Panel Cointegration Test

In the realm of panel modeling, the establishment of a cointegrated combination of variables hinges on a crucial requirement: the panel estimation residuals must exhibit both stationarity and integration at I (1). This section delves into scrutinizing the enduring cointegration relationship among variables. The examination is conducted through the application of Pedroni's (1999) four-panel and three-group mean panel cointegration statistics.

Table 3: Panel Cointegration Test Results (Pedroni Residual Cointegration Test)

Deterministic Intercept and Trend			
Null hypothesis:		**Weighted Statistic**	**Prob**
Panel v-Statistic	Within-dimension	-1.5914	0.9442
Panel rho-Statistic		1.0935	0.8629
Panel PP-Statistic		-4.9541***	0.0000
Panel ADF-Statistic		-5.2641***	0.0000
		Statistic	**Prob**
Group rho-Statistic	Between-dimension	0.9962	0.8404
Group PP-Statistic		-6.5532***	0.0000
Group ADF-Statistic		-5.7327***	0.0000
No Deterministic Trend			
Panel v-Statistic	Within-dimension	-0.6856	0.7535
Panel rho-Statistic		0.6364	0.7378
Panel PP-Statistic		-3.4669***	0.0003
Panel ADF-Statistic		-5.1801***	0.0000
		Statistic	**Prob**
Group rho-Statistic	Between-dimension	1.4329	0.9240
Group PP-Statistic		-3.8084***	0.0001
Group ADF-Statistic		-5.1837***	0.0000
No Deterministic Intercept or Trend			
Panel v-Statistic	Within-dimension	-0.6212	0.7328
Panel rho-Statistic		0.1570	0.5624
Panel PP-Statistic		-2.1330**	0.0165
Panel ADF-Statistic		-3.0814***	0.0010
		Statistic	**Prob**
Group rho-Statistic	Between-dimension	1.210111	0.8869
Group PP-Statistic		-2.187885**	0.0143
Group ADF-Statistic		-4.075139***	0.0000

Notes: The null hypothesis posits that there is no cointegration in the panel data, indicated by a p-value exceeding 5%. Conversely, the alternative hypothesis suggests the presence of cointegration in the panel data, characterized by a p-value below 5%. The symbols ***, **, and * indicate the level of significance at 1, 5, and 10 percent, respectively.

Table 3 delineates that when the calculated p-value falls beneath the 5% threshold of significance, two of the four panel statistics signal the repudiation of the null hypothesis, indicating an absence of cointegration ties among the variables. In a parallel vein, when the p-values dip below the 5% significance mark, the averages of two out of the three groups exhibit statistical significance, prompting the dismissal of the null hypothesis concerning the lack of a

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cointegration link. The findings unveil four distinctive phases marked by consistent trends: a deterministic trend with an intercept, the lack of a deterministic trend, and the absence of both a deterministic trend and intercept.

The proposition of cointegration garners substantial affirmation through a preponderance of statistically significant evidence, warranting its validation. The outcomes furnish compelling proof of a steadfast correlation among the factors scrutinized in the investigation.

Result of PMG Test

This segment delineates the approach applied in conducting panel economic research. The investigation employs the Pooled Mean Group (PMG) test, originally introduced by Pesaran et al. (1990), to assess the variables in the panel data. The PMG model incorporates panel data and incorporates the cointegration concept from the Autoregressive Distributed Lag (ARDL) model. This methodology recognizes potential fluctuations in intercepts and short-term coefficients in ASEAN CO_2 emissions, facilitating the determination of equivalent long-run coefficients. This stands as an advantageous departure from the MG method. Nevertheless, extant research suggests that ASEAN states do share a common long-term coefficient.

Table 4: PMG Test Results (ASEAN-5)

Long-run (Dependent Variable: LCO2)			
	Coef.	**Std Err.**	***p*-value**
LEC	-1.2302***	0.3445	0.001
LEG	-0.2686***	0.0302	0.000
LTR	-0.1698***	0.0345	0.000
LUR	-0.0296*	0.0173	0.094
Short-run (Dependent Variable: LCO2)			
LEC	1.7137**	0.7760	0.032
LEG	0.6525	0.4088	0.117
LTR	-0.2256	0.2003	0.266
LUR	-0.1134	0.0834	0.180

Notes: The symbols ***, **, and * represent the significance levels of 1%, 5%, and 10%, respectively.

Table 4 displays the outcomes of the PMG estimation at the panel level, presenting both long-run and short-run coefficients that unveil the intricate associations between explanatory and dependent variables. Notably, energy consumption (LEC) emerges as a significant driver of carbon dioxide emissions, with a coefficient indicating that a 1% upswing or downturn in energy consumption corresponds to a 1.2302% increase in CO_2 emissions.

In contrast, the coefficient highlights a robust interconnection between CO_2 emissions and economic growth (LEG). Specifically, there is a 0.2686% decline (or ascent) in CO_2 emissions for every 1% fluctuation in economic growth. Furthermore, the controlling factors of trade (LTR) and urbanization (LUR) exhibit a negative influence on the CO_2 emissions of the ASEAN-5 nations. The coefficient implies that a 1% surge in urbanization leads to a 0.0296% uptick in CO_2 emissions, while a 1% increase in trade corresponds to a 0.1698% decrease in

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CO_2 emissions. It's noteworthy, however, that urbanization lacks statistically significant impact on CO_2 emissions. Concerning CO_2 emissions, all explanatory variables demonstrate p-values below the 5% significance threshold, except for urbanization. Therefore, the results underscore a robust inverse relationship between these attributes and CO_2 emissions over an extended timeframe.

In the short run, none of the variables exhibit a statistically significant impact. Nevertheless, the pivotal factor influencing CO_2 emissions is energy utilization. A 1% shift in energy consumption results in a proportional rise or fall of 1.7137% in CO_2 emissions.

Table 5: Pooled Mean Group (PMG) of Individual Cross Section Estimation

ASEAN-5 Countries	Independent Variable			
	LEC	LEG	LTR	LUR
Malaysia	2.8001*** (0.000)	0.6326*** (0.000)	-0.8437*** (0.000)	1.8800*** (0.000)
Indonesia	3.3468** (0.018)	0.4121*** (0.004)	-0.1725*** (0.003)	-0.1351* (0.057)
Thailand	2.5132*** (0.004)	1.9812*** (0.000)	0.1027*** (0.002)	-0.1230*** (0.000)
Philippines	0.7804*** (0.001)	0.8070*** (0.001)	0.3643*** (0.000)	-0.3221*** (0.002)
Singapore	-0.8721 (0.221)	-0.5703 (0.618)	-1.9825*** (0.006)	-0.2936*** (0.001)

Notes: The asterisks ***, ** and * denote the significance level at 1, 5 and 10 percent respectively.

Employing the comprehensive Panel Mean Group (PMG) methodology in this study, individual-level effects are assessed. In the case of Malaysia, a positive correlation is observed among energy consumption, GDP growth, urbanization, and carbon dioxide emissions. The equations reveal that for every 1% uptick in energy consumption (LEC), there is a corresponding increase of 2.8001% in CO_2 emissions. Similarly, a 1% increase in economic growth (LEG) is associated with a 0.6326% increase in CO_2 emissions, and a 1% rise in urbanization (LUR) leads to a 1.8800% increase in CO_2 emissions. The estimates further indicate that a 1% increase in trade (LTR) results in a 0.8437% decrease in CO_2 emissions, underscoring the noteworthy influence of Malaysia's commerce on reducing CO_2 emissions.

In Indonesia, there exists a positive correlation between carbon dioxide emissions and the escalating trends of energy consumption and economic expansion, whereas a negative correlation is observed with increasing trade and urbanization. Associations with p-values below the 0.05 significance level are considered statistically significant. Specifically, energy consumption (2.5132%), economic growth (1.98812%), and trade (0.1027%) all contribute positively to the upsurge in CO_2 emissions in Indonesia. Conversely, urbanization exerts a significant adverse impact, leading to a reduction of 0.1230 emissions. Moving to Thailand, the factors of energy consumption, economic growth, and trade all positively influence the country's carbon dioxide emissions. Notably, urbanization in Thailand exhibits a statistically significant impact, resulting in a decrease in CO_2 emissions.

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In the Philippines, both energy consumption and economic growth positively affect carbon dioxide emissions, while trade also contributes to the upward trajectory of emissions. Interestingly, statistically significant evidence at a 5% significance level indicates that urbanization in the Philippines leads to a decrease in CO_2 emissions.

Contrarily, the overall impact on CO_2 emissions in Singapore is detrimental. Despite lacking statistical significance, both energy consumption and economic growth in Singapore have a negative impact on CO_2 emissions. However, the impact of CO_2 emissions in Singapore is statistically significant at a 5% level for both trade and urbanization control factors.

As per the statistics presented in Table 5, the Leading Emission Contributors (LECs) in the four ASEAN countries—Philippines, Malaysia, Indonesia, and Thailand—stand out as the primary culprits behind CO_2 emissions. However, Singapore, in contrast, has a minimal yet significant impact, effectively mitigating these emissions. Furthermore, while Singapore experiences a slight adverse effect from its Low Emission Growth, the emissions in Malaysia, Indonesia, Thailand, and the Philippines see an increase, exacerbating environmental degradation.

Analyzing the data reveals that the presence of Land-Use and Transportation Relationship (LTR) has a detrimental impact on CO_2 emissions in Malaysia, Indonesia, and Singapore. Conversely, in Thailand and the Philippines, LTR has a positive effect on reducing CO_2 emissions. Table 5 underscores that, overall, the implementation of Land Use Regulations (LUR) contributes to an improved environmental quality in Indonesia, Thailand, the Philippines, and Singapore, as evidenced by decreased levels of CO_2 emissions. However, it is noteworthy that in the short term, LUR in Malaysia actually leads to an increase in CO_2 emissions.

Result of Panel Non-Linear ARDL

Table 6: Panel NARDL Results (ASEAN-5)

Regressors	Coefficient	Std. Err.	t-Stat	*p*-value
Long-run Estimation				
LEC^{+}	-4.1754***	0.1201	-34.7497	0.000
LEC^{-}	2.7803***	0.3383	8.2194	0.000
LEG	-0.0800***	0.0045	-17.9723	0.000
LTR	-0.2049***	0.0027	-75.9896	0.000
LUR	0.4060***	0.0241	16.8317	0.000
Short-run Estimation				
LEC^{+}	1.8353	0.8449	2.1721	0.037
LEC^{-}	-1.7439	1.2915	-1.3504	0.186
LEG	0.3347	0.3771	0.8875	0.381
LTR	0.6267	0.7290	0.8597	0.396
LUR	-0.2546	0.1558	-1.6347	0.111

Notes: The notation LEC^{+} represents the partial sums of positive changes in energy consumption, while LEC^{-} denotes the partial sums of negative changes in energy consumption. The symbols ***, **, and * indicate the significance levels of 1%, 5%, and 10%, respectively.

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By employing the panel form of ARDL approach, an extended version introduced by Shin et al. (2014), this study aims to explore potential non-linear relationships between energy consumption and CO_2 emissions in the ASEAN-5 countries. The results of the asymmetry test and the NARDL estimates of long-run and short-run coefficients for each sample are presented in Table 6.

At a significant level of 0.05, the outcomes outlined in Table 6 reveal that an increase in energy consumption has an adverse impact on CO_2 emissions in the long term. This suggests a reduction of 4.1754% in CO_2 emissions for every 1% increase in energy use. The negative influence of energy consumption on CO_2 emissions is statistically significant at a 0.05 significance level. The data further indicates a positive correlation between a decrease in energy use and carbon dioxide emissions, with a 2.7803% increase in carbon dioxide release for every 1% decrease in energy use.

Thus, the findings highlight the existence of non-linear connections between energy consumption and CO_2 emissions. This discovery underscores the significant influence of energy usage on the ASEAN-5 region's capacity to achieve long-term reductions in CO_2 emissions.

Despite increasing consumption levels, the environment is likely to face reduced harm due to the growing utilization of renewable energy sources such as solar panels, wind turbines, and hydroelectric dams. Unlike fossil fuels, renewable energy sources do not emit carbon dioxide into the atmosphere. However, countries are shifting their focus from renewable energy to fossil fuels, driven by factors like the high costs associated with implementing environmentally sustainable technology. This shift is anticipated to result in an increase in carbon dioxide emissions. Furthermore, the economic development of the ASEAN-5 has a statistically significant negative impact on CO_2 emissions, with a significance level of 0.05. The coefficient suggests a direct relationship between economic growth and CO_2 emissions. Specifically, for every 1% change in economic growth, there is a corresponding 0.0800% decrease (or increase) in CO_2 emissions in the long term. This finding aligns with the earlier assumption derived from the PMG estimate in Table 5. The results emphasize the crucial role of economic expansion in reducing environmental degradation in the ASEAN-5 region. The transition of ASEAN-5 economies from a manufacturing-based economy with a focus on mass output to a service-based economy emphasizing knowledge-intensive sectors and services has played a pivotal role in this scenario.

Countries heavily reliant on industrial activities as the primary driver of their economy tend to produce significantly higher levels of greenhouse gas emissions compared to those with a focus on the service sector. Therefore, by advocating for environmentally sustainable economic practices, the ASEAN-5 region can potentially experience a reduction in carbon dioxide emissions. Urbanization exhibits a substantial long-term impact in mitigating CO_2 emissions, while other control variables like trade exert a notable adverse influence. Consequently, a 1% increase in urbanization results in a 0.4060% increase in CO_2 emissions, whereas a 1% expansion in trade leads to a 0.2049% decrease in CO_2 emissions. In summary, there is no statistically significant correlation between any of the variables and CO_2 emissions in the short

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run. A 1% increase in energy consumption, however, leads to a proportional increase of 1.8353% in CO_2 emissions, indicating that only the upward surge in energy consumption has a significant positive impact on these emissions. Presently, the energy consumption in the five ASEAN nations relies on fossil fuels for residential and commercial purposes. Nevertheless, active efforts are underway to transition towards sustainable energy sources that do not pose harm to the environment.

CONCLUSIONS AND POLICY IMPLICATIONS

This research endeavors to delve into the lasting and immediate impacts of energy consumption on carbon dioxide (CO_2) emissions across the five ASEAN states spanning the years 1990 to 2020. It takes into account both linear and non-linear factors. Findings from tests such as LLC, IPS, and Fisher-type unit root tests reveal varied initial values for the variables under scrutiny. Nevertheless, upon comparing their initial divergences, these variables demonstrate stationarity with a 98% level of significance. The Pedroni Residual cointegration test affirms enduring cointegration among the variables, signifying sustained connections between carbon dioxide emissions, energy consumption, economic growth, trade, and urbanization.

Applying the PMG technique to analyze both enduring and immediate outcomes, this research proposes that energy consumption, economic growth, and trade exert a favorable influence on environmental enhancement over the long term. However, in the short run, the study finds that energy utilization contributes to environmental deterioration. Non-linear ARDL findings indicate that heightened energy consumption decelerates environmental degradation, while a reduction in energy consumption accelerates it. Over time, a decline in energy usage correlates with a reduction in CO_2 emissions, whereas an upswing in energy usage results in an increase in CO_2 emissions. While business and economic development are acknowledged for their positive effects on the environment, urbanization appears to diminish environmental standards. It is acknowledged that the primary driver of environmental degradation is the upsurge in energy use, particularly the subsequent increase in carbon dioxide emissions, while the remaining parameters examined exert minimal or negligible impact.

The study emphasizes the pivotal role of decreasing energy consumption as a means to mitigate CO_2 emissions and foster sustainable economic growth, carrying significant policy implications. Governments within the ASEAN member states are urged to invest in projects and enact legislation that promotes energy efficiency. Striking a balance between economic expansion and environmental sustainability can be achieved by minimizing energy usage while maintaining production levels. This calls for resource allocation and research initiatives to support the growth and adoption of renewable energy sources, making substantial contributions to emission reduction. Overcoming the cost barrier associated with renewable energy technology is crucial. Governments can play a pivotal role by advocating for and incentivizing investments in wind, solar, and hydropower to enhance accessibility to these sources. Regulations endorsing environmentally friendly practices are essential, emphasizing the shift from finite to sustainable energy sources. Encouraging increased financial support for scientific research and technological advancements is vital to facilitate this transition.

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In the pursuit of both economic growth and environmental quality, prioritizing policies that consistently reduce CO_2 emissions is paramount. Economic strategies favoring cleaner energy sources can play a significant role in diminishing environmental damage. The imposition of restrictions on commerce, identified as a means to reduce CO_2 emissions, becomes imperative for governments aiming to promote trade while minimizing environmental impact.

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Biographical Sketch

The author currently resides in Kuching, Sarawak, Malaysia, and was born on July 29, 1997, in the same location. He is the eldest son of Hiew Nyong Joon and Sophia Anak Salim. His Primary Education was completed in the school year 2009 at *Sekolah Jenis Kebangsaan (Chung Hua) Pending*, followed by Secondary Education at *Sekolah Menengah Kebangsaan Pending* in 2014. During his Tertiary Education, he pursued a Bachelor's degree with Honors in Economics, major in Business Economics at the Faculty of Economics and Business, Universiti Malaysia Sarawak from 2017 to 2020.

Following his undergraduate studies, he furthered his education with a Master of Science in Economics, successfully completing the *Viva Voce* examinations on December 8, 2023. Opting to focus on a career in environmental management in Malaysia, he currently serves as an activities officer at the Malaysian Nature Society (Kuching Branch).

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