Avalaible online at http://journals.ums.ac.id, Permalink/DOI: 10.23917/jep.v24i1.23165

Jurnal Ekonomi Pembangunan: Kajian Masalah Ekonomi dan Pembangunan, 24 (2), 2023, 265-281

Nexus Between Economic Growth, Renewable Energy, Industry Value Added and CO_2 Emissions in ASEAN

Indah Susilowati[1], M. Silahul Mu'min[1], Hanny Qudsyina[1], Hesti Asri Wahyuni[1], Suci Rismawati[1], Hapsari Ayu Kusumawardhani[1], Md. Ruyel Miah[2]

[1]Faculty of Economics and Business, Diponegoro University

[2]School of Environment, Enterprise and Development, University of Waterloo, Canada

Corresponding Author: msilahulmumin@students.undip.ac.id

Received: October 2023 | Revised: November 2023 | Accepted: December 2023

Abstract

This study aims to identify the relationship between economic growth, renewable energy, and industrial value added to CO_2 emissions in ASEAN. The data used is panel data of 10 ASEAN countries from 2001-2020. This study uses the vector error correction model (VECM) for analysis. The estimation results show that CO_2 emissions are only influenced by the CO_2 variable itself in the previous period in the short term. In addition, economic growth and renewable energy significantly negatively affect CO_2 emissions in the long term. Economic growth has the largest contribution to reducing CO_2 emissions. The empirical findings also support the existence of the environmental Kuznets curve (EKC) in ASEAN. However, industrial value added has no significant effect on CO_2 emissions. This study has several policy implications. The government needs to 1) strengthen energy transition regulations to encourage the use of renewable energy, 2) increase investment in R&D to stimulate green technology innovation, and 3) protect the environment to mitigate negative externalities of economic activity.

Keywords: CO_2 emissions, Environmental Kuznets Curve (EKC), Industry value added, Renewable energy consumption, VECM

JEL classification: O13, O44, Q56

How to Cite: Susilowati I., Mu'min M. S., Qudsyina H., Wahyuni H. A., Rismawati S., Kusumawardhani H. A., Miah M. R. (2023). Nexus Between Economic Growth, Renewable Energy, Industry Value Added and CO_2 Emissions in ASEAN, 24(1), 265-281. doi:https://doi.org/10.23917/jep.v24i2.23165

DOI: https://doi.org/10.23917/jep.v24i2.23165

1. INTRODUCTION

The issue of environmental concerns has become a topic of grave global discourse and attention. Carbon emission has resulted in global warming and a rise in severe weather occurrences, threatening ecosystems (Miao & Li, 2023). The deteriorating quality of the environment has been acknowledged globally and has become an integral part of the discourse on worldwide climate change. The World Economic Forum (WEF), an international organization, has asserted that climate change is the most pressing issue significantly affecting the world (WEF, 2017). In the Kyoto Protocol, six emissions with substantial environmental impact have been identified, namely, CO2 (carbon dioxide), CH4 (methane), N2O (nitrous oxide), HFC (hydrofluorocarbon), PFC (perfluorocarbon), and SF6 (sulfur hexafluoride), with CO2 emissions standing out as the most prominent and rapidly increasing (Marselina & Prasetyo, 2023).

The increasing environmental issues, such as the threat of global warming and climate change, have directed attention and research toward the relationship between economic growth, energy consumption, and environmental pollution. The urgency of achieving economic growth and environmental sustainability is equally vital. The Institute for Essential Services Reform (IESR) explains that fossil fuels are still considered the primary source of energy security, while renewable energy is perceived as unreliable. As is well-known, the use of fossil fuels leads to pollution, especially in the form of CO2 emissions, which is detrimental to the environment. At the same time, using fossil fuels currently serves as a cornerstone of energy production and is directly linked to economic growth and development.

This aligns with the consensus reached on the Millennium Development Goals (MDGs) by 189 member states of the United Nations (UN) at the High-Level Conference in New York, subsequently followed by the Sustainable Development Goals (SDGs) initiated in 2016. The MDGs encompassed eight targets, one of which was the assurance of environmental sustainability. One indicator of this target's success is the quantity of CO2 emissions. This implies that governments must implement sustainable development alongside the preservation of the environment, both in the present and for future generations, with particular attention to controlling CO2 emissions (OECD, 2015)

CO_2 emissions have increased significantly in recent years, especially in ASEAN countries, due to human activities, fossil fuel use, and land use (Wilson, 2019). It is implied that mostly ASEAN countries, positioned at the stage of initial phase of industrialisation, exhibit higher levels of CO_2 emissions from fossil fuel use than those countries with more reliance on the service industry (ASEAN, 2021). Figure 1 explains that the development of ASEAN countries' GDP during 2001-2020 moves in the same direction as the increase in CO_2 emissions, which also reflects the decline in environmental quality. The data indicates that economic growth in ASEAN countries tends to cause negative environmental externalities.

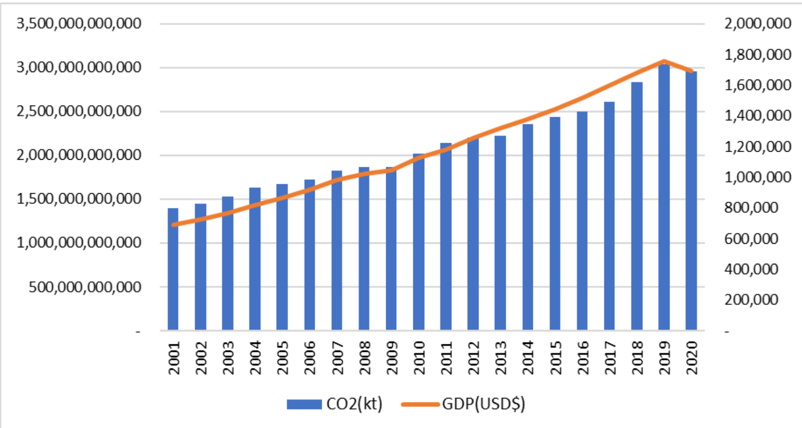

Figure 1. Trend of GDP and CO_2 Emissions in ASEAN 2001-2020

Source: World Bank, 2023

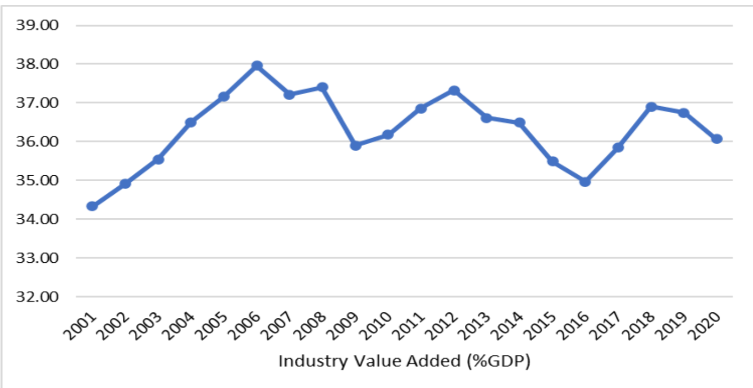

Figure 2. Trend of Industry value added in ASEAN 2001-2020

Source: World Bank, 2023

The ASEAN State of Climate Change Report (2021) explains that two sectors, namely 1) electricity and heat production and 2) manufacturing and transportation industries, have led to contribute CO2 emissions from energy use in ASEAN in the last two decades. Despite that, Figure 2 illustrates a contrasting trend in the value added by industries in ASEAN, which has experienced fluctuations and a declining overall trajectory. The highest average value added by the industrial sector in ASEAN was recorded at 37.96 percent in 2006, but this figure continuously decreased to 36.07 percent of the GDP by 2020.

Previous studies have attempted to investigate the relationship between industrial value added and CO2 emissions. The study by Jebli et al (2020) empirically found that industrial value added can reduce CO2 emissions, based on their sample estimation. However, Sulaiman et al. (2022) offered a contrasting perspective, focusing on a case study in India, emphasizing that industrial value added, particularly from the manufacturing sector, leads to environmental degradation through CO2 emissions. In the context of Indonesia, Kusumawardhani et al (2022) discovered a significant positive relationship between industrial value added and CO2 emissions. The existence of inconsistent findings and associations between industrial activities and CO2 emissions provides the foundational motivation for this study, which aims to explore the link between industrial value further added and CO2 emissions in the ASEAN countries.

The identification of the relationship between economic growth and environmental degradation can be approached from the perspective of the Environmental Kuznets Curve (EKC) theory. The Environmental Kuznets Curve (EKC) represents a curve that depicts the connection between economic growth and CO2 emissions, positing that a reduction in CO2 emissions occurs at a certain turning point, at which economic growth contributes to the decrease in CO2 emissions (Perman et al., 2011). This curve implies a causal relationship between economic growth and CO2 emissions, resulting in an inverted U-shaped curve (Aydin & Esen, 2017)

The Environmental Kuznets Curve (EKC) theory elucidates environmental degradation within developing countries in the early stages of industrialization. In a detailed manner, the EKC theory, as postulated by Kuznets, indicates that in the initial phases of economic growth, there is a discernible contribution to the escalation of environmental degradation. During this phase, industrialization development is accompanied by ecological deterioration due to the extensive utilization of natural resources (Yandle, 2004). After reaching a specific threshold, however, the direction of this relationship reverses. Subsequently, economic growth starts to mitigate environmental degradation. Hence, it explicitly shows that economic growth will be negatively correlated with environmental degradation in the long run. This phenomenon typically occurs during the post-industrialization phase, characterized by a transformation in the economic structure towards technology-driven sectors, thus encouraging improved environmental quality.

The statistical relationships of EKC reveal that, with advancing development and industrialization, environmental damage increases due to amplified natural resource consumption, heightened pollutant emissions, the operation of less efficient and relatively polluting technologies, an increased focus on material output expansion, and negligence regarding environmental concerns or ignorance of growth-related environmental impacts. Nevertheless, as economic growth continues and life expectancy improves, the significance of cleaner water, better air quality, and generally more pristine habitats becomes more pronounced, since individuals possess limited choices concerning how to allocate their income. During the post-industrial phase, cleaner technologies and the shift toward information-based and service-oriented activities are coupled with an increasing capacity and willingness to enhance environmental quality.

Several studies have aimed to investigate the EKC hypothesis, examining the relationship between economic growth and CO2 emissions. Ahmad et al (2021)conducted an empirical review of the presence of the environmental Kuznets curve in 11 developing countries, utilizing the fully modified ordinary least squares (FMOLS) and pooled mean group (PMG) methods to estimate long-term relationships. The dataset used encompasses panel data from the period 1992 to 2014. Their findings revealed an inverted U-shaped relationship between GDP per capita as a proxy for economic growth and CO2 emissions in the long term. Specifically, the existence of the EKC was identified in countries such as Brazil, China, India, Malaysia, Russia, and Thailand. In contrast, the EKC theory was not observed in other developing countries, including Mexico, the Philippines, Indonesia, and South Africa.

Thus far, transitioning to renewable energy sources is the primary alternative for reducing CO2 emissions. The ASEAN region has set ambitious targets for enhancing the utilization of renewable energy. IRENA & ACE (2022) report that ASEAN aims to achieve a 23% share of renewable energy in its total primary energy consumption by 2025, with 35% of installed renewable energy capacity. As of the end of 2018, the total installed electricity generation capacity in the ten ASEAN member states amounted to 252 GW, with 28% originating from renewable sources, predominantly hydropower. By 2020, this percentage had risen to 33.5% due to the increased use of solar photovoltaics (PVs)(ACE, 2020).

The significant role of renewable energy in reducing CO2 emissions is confirmed in the study by Shaari et al (2020), which examines the impact of renewable energy consumption and economic growth on CO2 emissions in selected countries, including Indonesia and Malaysia, among ASEAN members. Employing the pooled mean group method, their study found that renewable energy consumption generally leads to reductions in CO2 emissions in the short and long term. These findings are also corroborated by the study conducted by (Aimon et al., 2023) in the Asia-Pacific context. The key takeaway from their research is that renewable energy consumption and green economic growth can mitigate CO2 emissions, while non-renewable energy consumption tends to increase CO2 emissions. In their scenario analysis, the average reduction in emission levels for pessimistic, moderate, and optimistic scenarios is 15%, 32%, and 66%, respectively.

Considering the importance of mitigating CO2 emissions, the primary goal of the research is to examine the impact of economic growth, renewable energy, and industry value added on CO2 emissions in ASEANS. Therefore, as the urgency to CO2 emissions, the role of those become important. As shown in figure 1, the CO2 emissions in ASEAN has upward trend and moves in the same direction as GDP. For this reason, it is imperative to investigate the relationship between three variables used in this study on CO2 emissions. The key contributions of this paper to the existing literature are threefold. First, To the best of the authors' knowledge, the studies that examine the effect of economic growth, renewable energy and industry value added on CO2 emissions in ASEAN are not well-documented, so this research provide an additional empirical evidence related with study of CO2 emissions. Second, we examine not only the impacts of those variables on CO2 emission but also the impulse response and variance decomposition of CO2 emission. Third, this study offers policy implications and recommendations for reducing CO2 emissions in ASEAN.

2. RESEARCH METHOD

2.1 Data

This study employs CO2 emissions as a proxy for environmental degradation as the dependent variable (Kusumawardhani et al., 2022; Udeagha & Ngepah, 2023). There are three independent variables used in this study based on the Environmental Kuznets Curve (EKC) theory, namely Gross Domestic Product (GDP), Industry value added (IV), and Renewable Energy Consumption (REC). Table 1 provides a comprehensive description of all variables employed in this study.

The study relies on secondary data in the form of annual panel data from a research focus spanning ten ASEAN countries, which include Indonesia, Malaysia, Thailand, the Philippines, Singapore, Cambodia, Myanmar, Laos, Brunei Darussalam, and Vietnam. The observational period covers 2001-2020; all data sources are derived from the World Bank database.

Avalaible online at http://journals.ums.ac.id, Permalink/DOI: 10.23917/jep.v24i1.23165

Jurnal Ekonomi Pembangunan: Kajian Masalah Ekonomi dan Pembangunan, 24 (2), 2023, 265-281

Table 1. Variable Description

Variable	Notation	Definition	Unit	Source
Gross Domestic Product	LnGDP	Total value added of output produced in the economy	USD$	World Bank
Industry Value Added	IV	Total value added from mining, manufacturing, construction, electricity, water, and gas sectors	%	World Bank
Renewable Energy Consumption	REC	Percentage of renewable energy to total final energy consumption	%	World Bank
CO_2 Emissions	$LnCO_2$	CO_2 emissions from the burning of fossil fuel and cement manufacturing	Kt	World Bank

2.2 Research Model Specifications

This study aims to investigate the dynamic short-term and long-term relationships between economic growth, value-added industry, renewable energy consumption, and CO_2 emissions in ASEAN countries from 2001 to 2020. This paper employs the Vector Error Correction Model (VECM) methodology. The majority of the time series data is non-stationary, which makes direct regression estimations prone to "pseudo-regression.". Engle & Granger (1987) introduced the concept of cointegration, indicating the presence of a stable relationship among economic variables. Based on this, the VECM model can be applied. The basic VECM model can be expressed as follows (Breitung et al., 2004):

$$\Delta x_t = \Pi x_{t-1} + \Gamma_i \Delta x_{t-1} + ... + \Gamma_{i-1} \Delta x_{t-i+1} + \mu_t \quad (1)$$

As for = $-(I_k - A_1 - .... - A_p)$ and = $-(A_{j+1} + ... - A_i)$ where j = 1, 2, ..., i-1. Because Δx_t does not contain stochastic trends, assuming all variables can be of order one or I(1), Πx_{t-1} is the only one that includes variables I(1), so there is a cointegration relationship. Γ_j (j = 1, 2, ..., i-1) is the short-run parameter, and Πx_{t-1} is the long-run parameter.

The model specifications in this study adopt the approach of a prior investigation conducted by Kusumawardhani et al (2022), which examined environmental degradation in Indonesia based on industry value added, economic growth, and energy consumption. The model employed in this study is presented in the form of Vector Error Correction Model (VECM) equations.:

$$\Delta LnCO_{2it} = \varphi_1 + \sum_{j=1}^{n} \alpha_{1j} \Delta LnCO_{2i,t-j} + \sum_{k=1}^{n} \alpha_{2k} \Delta LnGDP_{i,t-k} + \sum_{l=1}^{n} \alpha_{3l} \Delta REC_{i,t-l} + \sum_{q=1}^{n} \alpha_{4q} \Delta IV_{i,t-q} + \xi_1 ECT_{i,t-1} + \mu_{i,t} \quad (2)$$

$$\Delta LnGDP_{it} = \varphi_2 + \sum_{j=1}^{n} \alpha_{1j} \Delta LnGDP_{i,t-j} + \sum_{k=1}^{n} \alpha_{2k} \Delta LnCO_{2i,t-k} + \sum_{l=1}^{n} \alpha_{3l} \Delta REC_{i,t-l} + \sum_{q=1}^{n} \alpha_{4q} \Delta IV_{i,t-q} + \xi_2 ECT_{i,t-1} + \mu_{i,t} \quad (3)$$

$$\Delta REC_{it} = \varphi_3 + \sum_{j=1}^{n} \alpha_{1j} \Delta REC_{i,t-j} + \sum_{k=1}^{n} \alpha_{2k} \Delta LnCO_{2i,t-k} + \sum_{l=1}^{n} \alpha_{3l} \Delta LnGDP_{i,t-l} + \sum_{q=1}^{n} \alpha_{4q} \Delta IV_{i,t-q} + \xi_3 ECT_{i,t-1} + \mu_{i,t} \quad (4)$$

$$\Delta IV_{it} = \varphi_4 + \sum_{j=1}^{n} \alpha_{1j} \Delta VAI_{i,t-j} + \sum_{k=1}^{n} \alpha_{2k} \Delta LnGDP_{i,t-k} + \sum_{l=1}^{n} \alpha_{3l} \Delta LnCO_{2i,t-l} + \sum_{q=1}^{n} \alpha_{4q} \Delta REC_{i,t-q} + \xi_4 ECT_{i,t-1} + \mu_{i,t} \quad (5)$$

$LnCO_2$ represents CO_2 emissions; LnGDP is Gross Domestic Bruto; REC is renewable energy consumption; IV is industry value added; $\varphi_{1,2,3,4}$ shows the intercept or constant; $\alpha_{1,2,3,4}$ is the coefficient that will estimate any potential effects of exogenous variables on endogenous variables; n is the lag optimum; $ECT_{i,t-1}$ is the correction term; $\xi_{1,2,3,4}$ is the coefficient of error correction which shows the speed of adjustment towards equilibrium; $\mu_{i,t}$ is error term; i represents cross-section i.e. ASEAN countries; t is period.

Before conducting estimations in this research, several preliminary tests will be performed on the model used, including 1) data stationarity test, 2) lag order selection test, 3) model stability test, and 4) cointegration test. The first step involves conducting a data stationarity test to ascertain whether the data for each variable contains unit roots. Stationary data is crucial to prevent the model estimation from spurious regression. Gujarati & Porter (2009) explain that stationary data will yield consistent and unbiased estimators. The fundamental equation for the unit root test is as follows:

$$\Delta Y_{it} = \beta Y_{it-1} + \sum_{j=1}^{p_i} \Delta Y_{it-j} + X`_{it}\delta + \mu_{it} \quad (6)$$

Where ΔY_{it-1} is the first order of country i in period t. μ_{it} is *error term*. The equation assumes that $\beta = \rho - 1$. The null hypothesis is accepted or Y has a unit root if $|\rho| = 1$. However, the null hypothesis is rejected if $|\rho| < 1$ or Y does not contain a unit root.

After ensuring the data is stationary, the next step involves conducting an optimal lag test to determine the appropriate number of lags in the utilized model. The optimal lag test is based on several criteria, namely FPE (Final Prediction Error), AIC (Akaike Information Criterion), SIC (Schwarz Information Criterion), and LR (Likelihood Ratio). The optimal lag length is determined by the smallest value of each criterion, denoted by an asterisk in each criterion. The lag length significantly impacts VAR estimation and can help prevent issues related to autocorrelation and heteroskedasticity (Wardhono et al., 2020).

The subsequent stage entails a model stability test. This test is conducted to ascertain whether the employed VAR model exhibits stability based on the roots of the polynomial function. A model is considered stable if the modulus of the roots of the polynomial function is less than one or, graphically, if all roots fall within the unit circle.

The next step involves cointegration testing. Cointegration testing is carried out to assess whether there is cointegrating relationship within the model. This study employs the Johansen Cointegration Test to determine cointegration in the model by comparing the probability values with the alpha level or between the trace statistic and critical values. The model is said to be cointegrated if the probability value is less than the alpha level or if the trace statistic exceeds the critical value. Thus, the hypothesis in the Johansen Cointegration Test is H_0: trace statistic < critical value, indicating the absence of a cointegrating relationship.

If cointegration relationships are identified in the model, estimations will be conducted using the vector error correction model (VECM). Subsequently, following the estimation via VECM, an analysis of the Impulse Response Function (IRF) and Variance Decomposition (VD) can be performed to elucidate the dynamic structure generated by the VECM methodology. The IRF analysis verifies how the endogenous variables respond in the event of shocks originating from the same and other endogenous variables. Moreover, the VD analysis is employed to expound the magnitude of the role played by endogenous variables in the extant endogenous variables within the model.

3. RESULTS AND DISCUSSION

3.1 Results

Table 2 presents a summary of descriptive statistics for all variables before applying logarithmic transformation. During the observation period, the average CO_2 emissions level in ASEAN countries amounted to 120,758 kt with a standard deviation of 139,845.9. Indonesia had the highest CO_2 emissions in 2019, reaching 605,290.6 kt. There was a trend of decreasing CO2 emissions in the ASEAN region during the COVID-19 pandemic. The mean and standard deviation of ASEAN GDP were approximately

208 billion US dollars and 219 billion US dollars, respectively. The GDP for ASEAN countries continued to rise over time, and this trend corresponded with the movement of CO_2 emission levels.

The mean and standard deviation of renewable energy consumption (REC) in ASEAN were 33.5 percent and 27.6 percent of total energy consumption, respectively. However, REC percentages tended to decrease during the observation period. Myanmar had the highest REC percentage, reaching 85.77 percent in 2009, while Brunei Darussalam had the lowest REC share, at less than 1 percent. Energy sector initial assessment reported that biomass, as renewable energy, became the main source for energy consumption in Myanmar accounting for almost 73% in 2009. It is aligned with Myanmar's energy policy framework to promote the wider use of new and renewable sources of energy (ADB, 2012).

Furthermore, the average industry value added (IV) in ASEAN countries remained relatively low at only 36.32 percent, with a standard deviation of 12.6 percent. Brunei Darussalam had the highest IV, reaching 74.11 percent in 2008. IV reflects the contribution of the private sector and the government to the overall GDP figure. $LnCO_2$, LnGDP, REC, and IV exhibit a long right-tail distribution with positive skewness values.

Table 2 also displays the correlation matrix coefficients between variables. It is evident that CO2 has a high positive correlation with GDP. Additionally, a positive correlation is observed between CO_2 and IV, while a negative correlation is found between CO2 and REC.

The preliminary study involved testing the stationarity of all variables. Table 3 presents the results of the stationarity tests utilizing the unit root test method, specifically the ADF-Fisher and PP-Fisher tests. The stationarity test results indicated that all variables in this study were non-stationary at the level. This was evidenced by the ADF-Fisher and PP-Fisher p-values exceeding the significance levels of 1%, 5%, and 10%. Following data differencing, the stationarity tests revealed that the data became stationary at the first difference level, as all p-values for each statistical test were less than the significance level. Therefore, all variables in this study are integrated into order 1(1).

Table 2. Descriptive Statistics and Correlation Matrix

Variable	CO_2	GDP	REC	IV
Mean	120758	2.08E+11	33.5512	36.32084
Median	52023.3	1.74E+11	30.365	34.66144
Maximum	605290.6	1.05E+12	85.77	74.11302
Minimum	997.81	5.27E+09	0.0000	10.20886
Std. Dev.	139845.9	2.19E+11	27.60463	12.60397
Skewness	1.331355	1.592157	0.339419	1.117969
Kurtosis	4.18119	5.947182	1.876879	4.42749
Correlation Matrix				
Variable	**$LnCO_2$**	**LnGDP**	**REC**	**IV**
LCO2	1			
LGDP	0.9292 (0.0000)***	1		
REC	-0.2728 (0.0001)***	-0.3253 (0.0000)***	1	
IV	0.1786 (0.0114)**	0.0673 (0.3438)	-0.5811 (0.0000)***	1

Notes : ***),**), *) significant at 1%, 5%, 10% respectively

Table 3. Unit Root Test Results

Variable	ADF-Fisher		PP-Fisher	
	Level	1st difference	Level	1st difference
LCO2	17.6632 (0.6096)	82.3100*** (0.0000)	12.1096 (0.9123)	88.0003*** (0.0000)
LGDP	7.52150 (0.9946)	33.8758** (0.0270)	5.15499 (0.9996)	36.27832** (0.0143)
IV	17.2075 (0.6395)	77.0507*** (0.0000)	30.6227 (0.0604)	103.998*** (0.0000)
REC	22.0768 (0.3364)	79.1883*** (0.0000)	16.1723 (0.7059)	97.9136*** (0.0000)

Notes : ***),**), *) significant at 1%, 5%, 10% respectively

Table 4. Optimum Lag Test Results

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-134.3097	NA	0.000118	2.305161	2.398078*	2.342895
1	-108.0869	50.26023*	9.94e-05*	2.134782*	2.599364	2.323451*
2	-103.6221	8.259902	0.000121	2.327036	3.163283	2.66664
3	-90.35273	23.66378	0.000126	2.372545	3.580459	2.863085
4	-83.21135	12.25936	0.000147	2.520189	4.099768	3.161663
5	-71.96644	18.55411	0.00016	2.599441	4.550685	3.39185
6	-58.04952	22.03512	0.000168	2.634159	4.957068	3.577503
7	-42.68409	23.30422	0.000172	2.644735	5.33931	3.739014

Notes: *) lag optimum selected

Determining the optimal lag length is crucial in Vector Error Correction Model (VECM) analysis. Selecting the appropriate lag length is essential to mitigate issues related to autocorrelation and heteroskedasticity Wardhono et al (2020). Table 4 presents the results of the optimal lag length tests based on five criterions in this study. All criterions show lag order of VECM model is 1 which is indicated by (*). Those can be found in the smallest values of the Final Prediction Error (FPE), Akaike Information Criterion (AIC), Hannan-Quinn (HQ), and the highest value in sequential modified LR test statistic (LR) as well. Subsequently, the estimation will be conducted using a lag length of 1.

The estimation of the vector error correction model necessitates an assessment of model stability through the computation of the roots of the characteristic polynomial, commonly referred to as the roots of the characteristic polynomial. The VECM model is deemed stable when the absolute values of the roots of the polynomial function are less than 1. Table 5 presents the results of the model stability test, revealing that the model in this study satisfies the stability conditions for Vector Auto-Regressive (VAR). Thus, the VECM can be accepted for the model estimation

Table 5. Model Stability Test Results

Root	Modulus
0.828804	0.828804
0.558485	0.558485
-0.343795	0.343795
-0.285019 - 0.068903i	0.29323
-0.285019 + 0.068903i	0.29323
0.290609	0.290609
0.060099 - 0.254760i	0.261753
0.060099 + 0.254760i	0.261753

Next, a cointegration test was conducted to determine whether the model in this study exhibits long-term relationships among the variables.

Cointegration testing in this study employed Johansen's cointegration test, comparing the trace statistic values to critical values. The results of the cointegration test in Table 6 indicate the presence of three cointegrating equations at significance levels of 1%, 5%, and 10%, thus rejecting the null hypothesis of no cointegration relationship among LnCO2, LnGDP, REC, and IV. Based on the cointegration test results, it can be inferred that the model utilized demonstrates cointegration relationships. Consequently, further estimation will be performed using VECM at lag 1.

This study also employs Granger causality tests to examine the causal relationships among variables. Table 7 demonstrates that the majority of variables indicate a unidirectional causal relationship. The variable REC exhibits a one-way causal relationship with LnCO_2 with probability values below the significance level, whereas LnCO2 does not influence REC in return. Additionally, CO_2 emissions only have a unidirectional impact on IV and vice versa. Meanwhile, no causal relationship is found between LnGDP and LnCO_2.

Table 6. Cointegration Test Results

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	Critical Value	Prob.
α = 1%				
None *	0.3039	167.6570	40.1749	0.0000
At most 1 *	0.2953	106.0800	24.2760	0.0000
At most 2 *	0.1913	46.5912	12.3209	0.0000
At most 3 *	0.0598	10.4864	4.1299	0.0014
α = 5%				
None *	0.3039	167.6570	46.5716	0.0000
At most 1 *	0.2953	106.0800	29.5135	0.0000
At most 2 *	0.1913	46.5912	16.3619	0.0000
At most 3 *	0.0598	10.4864	6.9406	0.0014
α = 10%				
None *	0.3039	167.6570	37.03536	0.0000
At most 1 *	0.2953	106.0800	21.77716	0.0000
At most 2 *	0.1913	46.5912	10.47457	0.0000
At most 3 *	0.0598	10.4864	2.976163	0.0014

Table 7. Granger Causality Test

Null Hypothesis:	Obs	F-Statistic	Prob.
LnGDP does not Granger Cause LnCO_2	190	1.53884	0.2163
LnCO_2 does not Granger Cause GDP		2.72895	0.1002
REC does not Granger Cause LnCO_2	190	9.68035	0.0022***
LnCO_2 does not Granger Cause REC		0.32925	0.5668
IV does not Granger Cause LnCO_2	190	0.89779	0.3446
LnCO_2does not Granger Cause IV		11.0259	0.0011***
REC does not Granger Cause LnGDP	190	70.7924	1.00E-14***
LnGDP does not Granger Cause REC		0.3303	0.5662
IV does not Granger Cause LnGDP	190	65.6202	7.00E-14***
LnGDP does not Granger Cause IV		13.2215	0.0004***
IV does not Granger Cause REC	190	2.60638	0.1081
REC does not Granger Cause IV		8.16525	0.0048***

Notes : *),**), *) significant at 1%, 5%, 10% respectively**

Table 7. VECM Estimation Results

Dependent Variables	Short Run				Long Run
	$\Delta lnCO_2$	ΔLnGDP	ΔREC	ΔIV	$\Delta lnCO_2$
$\Delta lnCO_{2,t-1}$	0.2969*** [3.114]	-0.0393 [-1.5131]	-2.2942 [-1.4088]	0.0174 [0.0104]	.....
$\Delta LnGDP_{t-1}$	-0.1905 [-0.6000]	0.4946*** [5.7171]	10.8580** [2.0026]	-7.3295 [-1.3191]	-1.7979** [-2.2297]
ΔREC_{t-1}	0.0058 [1.0506]	-0.0008 [-0.5153]	-0.0336 [-0.3549]	0.04501 [0.4635]	-1.0914*** [-5.9473]
ΔIV_{t-1}	-0.0019 [-0.4472]	0.0001 [0.0580]	-0.0079 [-0.1060]	0.1283* [1.6782]	0.37731 [1.0238]
ECM_{t-1}	-0.0010*** [-3.2545]	-0.0004*** [-4.9949]	0.0223*** [4.2799]	-0.0109** [-2.0495]	.....
F-Statistic	7.0929	27.2922	6.91244	2.43786	

Notes : ***),**), *) significant at 1%, 5%, 10% respectively

The VECM model estimates can be found in Table 7. It is observed that the ECT_{t-1} coefficient is statistically significant and negative for equation (2), indicating that there is a long-term convergence towards achieving equilibrium for $LnCO_2$ with other variables in the model. In the short term, CO_2 emissions are only influenced by CO_2 emissions in the previous period with a coefficient of 0.2969. This implies that a 1% increase in CO_2 emissions in the previous period will increase CO_2 emissions in the subsequent period by 0.2969%. This suggests that the current level of CO_2 emissions will contribute to environmental degradation in the following year. On the other hand, LnGDP, REC, and IV do not exhibit significant effects in the short term due to p-values exceeding the significance levels of 1%, 5%, and 10%.

The long-term VECM estimation shows a significant negative effect of GDP on CO_2 emissions with a coefficient of 1.7979. This result indicates that a 1% increase in GDP is predicted to reduce CO_2 emissions in ASEAN by 1.7979%. Another significant relationship is observed between REC and $LnCO_2$ in the long term, with a coefficient of -1.0914. This estimation implies that a 1% increase in renewable energy consumption as a percentage of total final energy consumption will reduce CO_2 emissions by 1.0914% during the observation period from 2001 to 2020. However, the results of this study do not show a significant influence of industry value added on CO_2 emissions.

This study employs an analysis of impulse response functions to identify the response of CO_2 emissions to a one-standard-deviation shock in CO_2 emissions, economic growth, renewable energy consumption, and industry value added over a 15-year horizon. The IRF results are presented in Figure 5. In this figure, the horizontal axis denotes the number of impulse response periods, the vertical axis illustrates the intensity of the response, and the vertical lines represent the impulse response curve.

Figure 3(a) illustrates a positive response of CO_2 emissions to shocks in its emissions variable throughout the period. The response of CO_2 emissions increases relatively from 1st year to 4th year, reaching 0.131148. In 5th year, the CO_2 response exhibits a linear decreasing trend, ultimately getting a relatively low-intensity response of 0.117200 in 15th year. These impulse response results indicate that the positive impact of CO_2 on its variable increases in the short term but diminishes in the long term. The CO_2 emissions response also confirms the short-term direction of significant positive influence as estimated by the VECM.

Figure 3(b) displays the response of CO_2 emissions to fluctuations in GDP, which are relatively volatile. CO_2 emissions exhibit a negative response from 1st year to 11th year, with the minimum effect occurring in 3rd year at -0.006035. The results imply that activities aimed at increasing production capacity, reflective of economic growth, in ASEAN countries are capable of mitigating CO2 emissions. The mitigation can be attributable to the transformation of production activities towards an environmentally friendly technologies. However, the response of CO_2 emissions tends to be positive in 12^{th} year and it continues until the 15th year.

A positive response of CO_2 emissions is also observed in Figure 3(c), indicating shocks in renewable energy consumption over 15 years. CO_2 emissions only respond in 2nd year, with an intensity response of 0.009547. Shocks in renewable energy consumption elicit a continually increasing response intensity up to 15th year, reaching a value of 0.028382. Conversely, Figure 3(d) demonstrates a negative response of CO_2 emissions to shocks in industry value added. This implies that industry value added has a negative influence, both in the short and long term, on CO2 emissions in the ASEAN countries.

This study also employs Variance Decomposition (VD) analysis to compare the percentage contributions of CO2 emissions, economic growth, renewable energy consumption, and industrial value-added to changes in CO2 emissions in ASEAN countries over a 10-year period. The results of the variance decomposition analysis are presented in Table 8. It is known that the largest contribution to CO2 emissions in the first period is attributed to CO2 emissions itself, accounting for 100%. In general, the contribution is predominantly dominated by the CO2 emissions variable up to the tenth period, reaching 97.62%. The subsequent contributions are provided by renewable energy consumption, industry value added, and economic growth, amounting to 1.77%, 0.49%, and 0.11%, respectively. The VD results can support an analysis that draws attention to the potential environmental degradation associated with CO2 emissions.

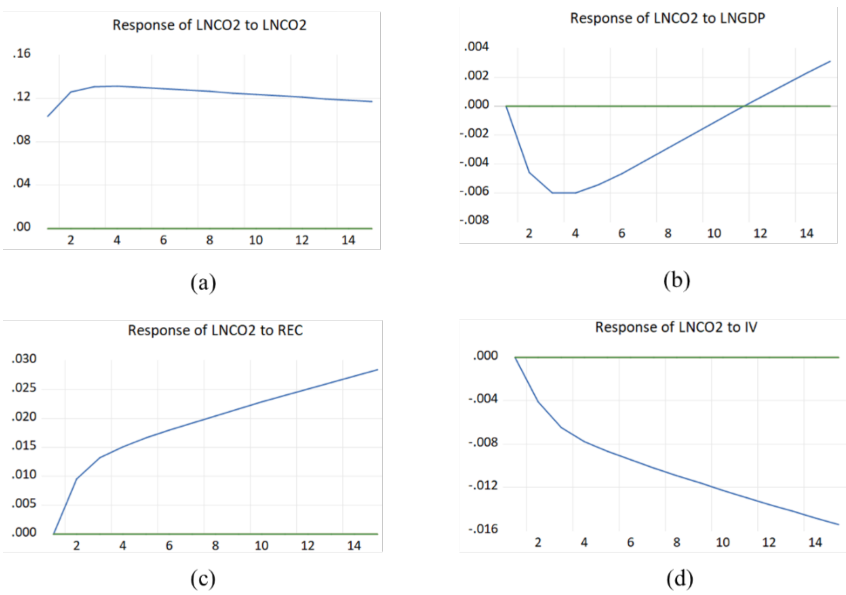

Figure 3. Impulse Response Function (IRF) Results

Table 8. ***Variance Decomposition*** **(VD)** ***Results***

Period	S.E.	LnCO2	LnGDP	REC	IV
1	0.103276	100.0000	0.000000	0.000000	0.000000
2	0.163113	99.51349	0.079876	0.342547	0.064082
3	0.209662	99.1347	0.131207	0.599427	0.134666
4	0.247957	98.85343	0.152963	0.798723	0.19488
5	0.280755	98.62308	0.157213	0.97177	0.247939
6	0.309655	98.41674	0.152104	1.13371	0.297451
7	0.335641	98.2201	0.142393	1.291894	0.345618
8	0.35935	98.02537	0.130841	1.450107	0.393677
9	0.381223	97.82818	0.119088	1.610407	0.44233
10	0.401576	97.62594	0.108128	1.773956	0.491978

3.2 Discussion

3.2.1 Economic Growth and CO_2 Emissions

The results of this study reveal a significant negative relationship between GDP and CO_2 emissions in the long term. It is implied that the economic growth in ASEAN plays a pivotal role in reducing environmental degradation, which in turn can promote the sustainable development. This study further supports the environmental Kuznets curve hypothesis, wherein long-term economic growth leads to improved environmental quality. The empirical evidence of the negative relationship between economic growth and CO_2 emissions in this study is consistent with previous research by Ahmad et al (2021) in developing countries. Specifically, the findings indicate empirical support for the EKC hypothesis in Brazil, China, India, Malaysia, Russia, Thailand, and Turkey. The existence of the EKC hypothesis has also been identified in various studies with different focuses, such as (Shahbaz et al., 2019) in Vietnam, (Ansari et al., 2020) in Asian countries, (Boubellouta & Kusch-Brandt, 2020) in European countries, (Prasetyanto & Sari, 2021) in Indonesia, and (Cahyadin et al., 2021) in Developing countries.

The estimation results in this study demonstrate that GDP has the largest coefficient value concerning CO_2 emissions. This implies that the production of goods and services in ASEAN is pivotal in reducing CO2 emissions. This can be comprehended in light of the transformation of production activities grounded on innovation and ecologically sustainable technologies. Furthermore, the impulse response analysis results suggest the need to strengthen the economic fundamentals of ASEAN countries to prevent shocks to GDP from worsening the CO_2 emission situation. Cahyadin et al (2021) explained that the dynamics of the global economy significantly will influence the environmental quality as developing countries like ASEAN actively elevate their economies to a global scale resulting in an increase in foreign investment, globalization, and economic openness. In addition, ASEAN countries are highly vulnerable to economic shocks from the global economy, such as international financial crises and fluctuations in oil prices, which subsequently affect GDP and CO_2 emissions (Roespinoedji et al., 2020). However, this study contradicts the empirical findings of Mendonça et al (2020) who found a positive relationship between GDP and CO_2 emissions in the case of countries with large economies, including Indonesia and Malaysia. Their study has additional implications, suggesting that populous countries are more likely to generate greater greenhouse gas emissions. Thus, CO_2 emissions are expected to continue rising due to economic activities and population growth if no efforts are made to reduce them.

The Environmental Kuznets Curve theory explains that countries in the industrialization phase tend to heavily exploit resources to boost economic activities, resulting in inefficiencies and negative environmental externalities.

Since most ASEAN countries are developing countries, their economic activities are largely extractive. CO_2 emissions can be reduced by shifting economic activities towards technology-based and innovative approaches to support developmental progress and industrialization with cleaner and more efficient technologies. Clean and environmentally friendly technology and innovation are expected to enhance economic productivity without causing higher CO_2 emissions. ASEAN Center For Energy (2022) reports that clean coal technology can promote energy transition and quality environment in ASEAN. In detail, the implementation of highly efficient modern supercritical and ultra-supercritical coal planst emit almost 40% less CO_2 than subcritical plants. The finding of Chien et al (2023) confirms that technological innovation and clean energy play a role to lower CO_2 emissions and ecological footpirnts. Therefore, ASEAN governments must implement policies to develop technology and innovation, particularly in the industrial sector. Solutions may include attracting foreign investors to fund technology development needs and increasing government expenditure on research and development.

3.2.2 Renewable Energy Consumption and CO_2 Emissions

The findings of this study provide a significant clarification of the role of renewable energy in reducing CO_2 emissions for the long-term achievement of sustainable development. The utilization of renewable energy reflects the use of non-fossil fuels, thereby reducing CO_2 emissions. Voumik et al (2023) have demonstrated that CO_2 emissions in Asian countries tend to be caused by the use of non-renewable energy sources. This study's results are further confirmed by the findings of Mukhtarov et al (2023), who provide empirical evidence of a significantly negative long-term impact of renewable energy consumption on CO_2 emissions. Similar results can be found in earlier studies for different regions, such as (Rahman et al., 2022) in advanced economies, (Bhattacharya et al., 2017) in both advanced and developing nations, (Aimon et al., 2023)in the Asia-Pacific region, (Aziz et al., 2021) in MINT countries, and (Leitão et al., 2021) in BRICS nations. Additionally, the findings of Shaari et al (2020) strengthen the argument that the use of renewable energy can effectively reduce CO_2 emissions, especially in lower-middle-income countries. Therefore, the findings in this study have implications that call for a transition to renewable energy through environmentally friendly energy sources by ASEAN countries to mitigate negative externalities on environmental quality.

Since climate change has become a global concern, the transition to renewable energy has been continuously pursued as a solution to create environmentally friendly energy production. Adopting renewable energy offers multidimensional benefits as a crucial tool for ensuring energy supply, advancing technology development, facilitating regional development, and creating new job opportunities (Saboori et al., 2022). Furthermore, Taşkın et al (2020) have shown that renewable energy can accelerate sustainable economic growth by reducing environmental degradation. This means that the transition to renewable energy can be pivotal in fostering a more sustainable economy without perpetuating CO_2 emissions. World Bank data reveals that the average percentage of renewable energy consumption in ASEAN countries was only approximately 25.89% in 2020. The highest share of renewable energy consumption was dominated by three countries: Myanmar at 59.75%, Cambodia at 51.41%, and Laos at 49.91%. Conversely, Brunei Darussalam and Singapore had the lowest percentage of renewable energy consumption, at only 0.01% and 0.92%, respectively. This underscores the need for ASEAN countries to increase the rate of renewable energy utilization.

At COP26, ASEAN countries committed to achieving zero emissions, including the phasing out of coal and methane reduction. The achievement of zero emissions is closely tied to the role of the renewable energy sector. The ASEAN Plan Of Action For Energy Cooperation (APAEC) Phase 2 report indicates that ASEAN countries target 23% renewable energy in the total energy mix and 35% for installed capacity by 2025. Efforts to transition to renewable energy to meet these targets can be supported, in part, by providing funding for various renewable energy projects. So far, the total percentage of clean energy investment in developing countries has only reached a quarter of the global total (IRENA & ACE, 2022). According to the 7th ASEAN Energy Outlook (2022), investment in renewable energy is projected to account for only one-third of the total investment needed by ASEAN countries by 2050 under the baseline scenario. Therefore, the transition to renewable energy to support net zero emissions by 2050 needs substantial investment in line with the established targets. ASEAN governments must provide a simpler, more transparent investment policy framework to build investor confidence. Stimulative policies in the form of subsidies are crucial to attract more investment in the renewable energy sector, such as feed-in tariff (FIT) policies.

3.2.3 Industry value added and CO_2 Emissions

This study also aims to identify the relationship between industry value added and CO_2 emissions in the ASEAN region from 2001 to 2020. The results of this study do not reveal any significant impact of industry value added on CO_2 emissions in both the short and long term. The positive yet non-significant influence of industry value added on CO_2 emissions is also corroborated by the study conducted by Jebli et al (2020) in the case of upper-income countries, including Singapore. However, the findings from the study by Jebli et al (2020) using Granger causality analysis indicate the existence of bidirectional Granger causalities between industry value added and CO_2 emissions in the long term for lower-middle income and upper-middle income countries. These results are also affirmed by this study's impulse response analysis, which demonstrates that a shock in industry value added leads to a negative response in CO_2 emissions from the first year to the fifteenth year.Based on these empirical findings, industrial activities in ASEAN countries have not yet been able to accommodate the adverse impacts on CO_2 emissions. There is a need to transition to energy-efficient and advanced technology-based industrial activities to reduce the emissions produced.

The "Investing in ASEAN" report highlights the substantial potential for developing the industrial sector in ASEAN. This potential can be observed in the production processes, such as implementing Industry 4.0 technologies, including advanced robotics, 3D printing, and real-time digital factory simulations. The development of these technologies aims to encourage the manufacturing industry to produce high-value-added products such as machinery and electronics. So far, Singapore, Malaysia, and Vietnam have prioritized advancing their advanced manufacturing systems. This is evident from the publication of industry roadmaps and investment plans and strategies in areas such as the smart industry, the Internet of Things (IoT) industry, advanced robotics, and cloud computing applications for manufacturing. The adoption of advanced technologies and improved operational efficiency can enable the manufacturing sector to operate in a decarbonized manner and support the achievement of zero emissions by 2030.

4. CONCLUSIONS

This study is initiated in response to the increasing environmental degradation phenomenon, as reflected in the levels of CO_2emissions. The primary objective of this study is to identify the relationship between economic growth, renewable energy consumption, and industry value added concerning CO_2 emissions. Panel data for ASEAN countries during the period 2001-2020 is used for this analysis. The Vector Error Correction Model (VECM) is employed to investigate the short-term and long-term relationship among the variables. Overall, The findings of this study demonstrate the crucial roles of economic growth and renewable energy in reducing CO_2 emissions in the ASEAN region. This suggests that the economic growth path in ASEAN needs to be directed towards the ecological excellent through the augmenting of sustainable technologies, while the use of renewable energy crucially should be enhanced to achieve sustainable economy. It is imperative for

ASEAN to promote renewable energy resources into its energy sector and to reduce the reliance of non-renewable energy resources. In addition, the findings of this study also confirm the environmental Kuznets curve hypothesis in the long run

Our empirical findings provide valuable insights for identifying the determinants of CO_2 emissions in ASEAN countries. These insights can guide policymakers in ASEAN to formulate strategic measures toward achieving more sustainable economic growth. Based on this, this study attempts to recommend several policies. First, governments in ASEAN countries should strengthen energy transition regulations, especially by offering attractive policies such as feed-in tariffs (FIT) subsidies to incentivize investment in renewable energy sectors. Additionally, incentives in the form of tax holidays can be granted to pioneering industries to boost the use of renewable energy in their production processes. Second, increasing research and development (R&D) investment is necessary to stimulate innovation and create various eco-friendly technologies, reducing dependence on advanced nations for technological production. Third, governments should make concerted efforts to protect the environment from negative externalities arising from different economic activities, particularly in industrial and metropolitan areas.

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