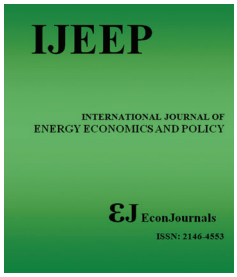


International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2025, 15(1), 589-597.

Carbon Emission Control Mechanism: Analysing the Role of Growth of the Transportation and Warehousing Sector, GDP, and Renewable Energy Consumption

Heru Wahyudi[1]*, Driya Wiryawan[1], Sandra Mei Leny[1], Usamah Bin Said[2], Abdurahman[3]

[1]Faculty of Economics and Business, University of Lampung, Bandar Lampung, Indonesia, [2]Faculty of Economics and Business, Muhammadiyah University of Pekajangan Pekalongan (UMPP), Central Java, Indonesia, [3]Faculty of Administrative Sciences, University Madura, Pamekasan, Indonesia. *Email: heru.wahyudi@feb.unila.ac.id

Received: 12 September 2024 **Accepted:** 10 December 2024 **DOI:** https://doi.org/10.32479/ijeep.18018

ABSTRACT

This study explores the relationship between Growth of the Transportation and Warehousing Sector, Gross Domestic Product (GDP), and Renewable Energy Consumption on carbon emissions in Indonesia. This study is motivated by the global challenge of reducing carbon emissions to address climate change, especially in developing countries that face a dilemma between economic development and environmental sustainability. Using the Fully Modified Ordinary Least Squares (FMOLS) approach with time series data from 2011 to 2023, the results show that Growth of the Transportation and Warehousing Sector has a significant positive effect on carbon emissions, reflecting the increase in fossil energy consumption caused by increased logistics and distribution activities. Gross Domestic Product (GDP) was also found to be significantly positively related to carbon emissions, supporting the Environmental Kuznets Curve (EKC) hypothesis, which states that in the early stages of economic growth, emissions tend to increase along with higher fossil energy use. In contrast, Renewable Energy Consumption shows a negative and significant effect on carbon emissions, indicating that the transition towards clean energy sources can substantially reduce carbon emissions. This research confirms the need for low-carbon technology adoption, accelerated investment in renewable energy, and strengthened environmental policies to reduce the impact of carbon emissions. The findings provide relevant empirical insights for policymakers in designing climate change mitigation strategies and a sustainable energy transition, in line with Indonesia's carbon emission reduction target of 29% by 2030 and achievement of net zero emissions by 2060.

Keywords: Carbon Emissions, Growth of the Transportation and Warehousing Sector, Gross Domestic Product, Renewable Energy Consumption, Indonesia, Fully Modified Ordinary Least Squares
JEL Classifications: Q56, O44, R40, L91

1. INTRODUCTION

Climate change is one of the biggest challenges of the 21st century, with carbon emissions as the main driver of rising global temperatures that damage ecosystems, destabilize economies and increase the risk of natural disasters. The Intergovernmental Panel on Climate Change (IPCC) report confirms that greenhouse gas emissions need to be significantly reduced to limit temperature rise to 1.5°C by the end of the century (Forster et al., 2023).

Indonesia, as one of the largest carbon-emitting countries in Southeast Asia, faces the challenge of balancing the needs of economic development and environmental sustainability. The transport and storage sector in Indonesia contributes significantly to the Gross Domestic Product (GDP), but is also one of the largest sources of carbon emissions. According to (Wang et al., 2022) emissions from the transport sector account for more than 25% of total national carbon emissions, largely due to reliance on fossil fuels. The growth of this sector is driven by urbanisation, increased logistics activities, and rapid e-commerce penetration, but has not been matched by

the adoption of low-carbon technologies (Mulyani and Widodo, 2023).

In addition, the Environmental Kuznets Curve (EKC) theory provides a perspective that the relationship between GDP and carbon emissions is dynamic, where in the early stages of economic growth, emissions tend to increase along with the intensification of economic activity. However, at a certain level of income, countries are able to reduce emissions through investment in environmentally friendly technologies and the implementation of stricter policies. Studies conducted in developed countries, such as the European Union, show that strong environmental policies, such as carbon taxes and renewable energy subsidies, are effective in decoupling the relationship between economic growth and carbon emissions (Dinda, 2022). However, in developing countries such as Indonesia, structural challenges, including limited green investment and dependence on fossil energy, complicate the transition to a low-carbon economy (Haque et al., 2023).

Renewable energy consumption is becoming one of the globally recognised solutions to reduce carbon emissions. Countries such as Norway and Germany have shown success in reducing emissions through increasing the share of renewable energy in the national energy mix (Nordhaus, 2021). In contrast, despite Indonesia's vast renewable energy potential including 207 GW of solar and 23 GW of geothermal, its utilisation is still at a low level of around 14% of total national energy demand. This underscores the need for more progressive policies to accelerate the adoption of renewable energy in Indonesia (Nugroho et al., 2023).

This study aims to empirically analyze the relationship between transport and storage sector growth, GDP, and renewable energy consumption on carbon emissions in Indonesia. Using the Fully Modified Ordinary Least Squares (FMOLS) econometric approach, this study evaluates the long-term relationship between variables based on time series data from 2011 to 2023. The findings of this study are expected to make a significant contribution to the environmental economics literature, while offering relevant policy recommendations to support Indonesia's energy transition and low-carbon development.

2. LITERATUR REVIEW

2.1. Growth of the Transportation and Warehousing Sector

The growth of the transportation and warehousing sector is directly linked to the increase in carbon emissions, mainly due to the significant dependence on fossil fuels in transport operations and logistics infrastructure. Globally, the transport sector contributes around 24% to total carbon dioxide emissions from energy combustion, of which road transport accounts for around 74% of the total (González et al., 2022). In Indonesia, the growth of this sector is driven by the urbanisation process, e-commerce expansion, and infrastructure development (Setiawan and Mahendrawati, 2023). While these developments improve logistics efficiency, they also result in increased energy consumption and carbon emissions. Road and air transport activities in the distribution of goods are major contributors to Carbon Emissions, while the warehousing sector contributes through high energy requirements for refrigeration and storage.

The study by (Abdelrahman et al., 2022) shows that the growth of the Transportation and Warehousing Sector has the potential to exacerbate the impacts of climate change. Strategic measures such as accelerating the transition to electric vehicles, using renewable energy in warehousing operations, and applying digital technology to optimise logistics routes have significant potential to reduce carbon emissions. However, the implementation of these strategies requires substantial investment and cross-sector coordination to ensure a balance between economic growth and environmental sustainability.

2.2. Gross Domestic Product (GDP)

The relationship between GDP and Carbon Emissions has been a major focus in the environmental economics literature. The Environmental Kuznets Curve (EKC) theory proposed by Grossman and Krueger (1995) hypothesizes that Carbon Emissions tend to increase in the early stages of Economic Growth, but will decline after reaching a certain income level, due to the transition towards environmentally friendly technology. (Chen et al., 2021) support the EKC Theory hypothesis in developed countries, where rising incomes allow for greater investment in clean technologies as well as the implementation of emission control policies.

On the other hand, in developing countries, Economic Growth is often positively correlated with increased Carbon Emissions. (Arouri et al., 2022) found that middle-income countries, especially those still dependent on fossil energy, experienced an increase in Carbon Emissions due to rapid Economic Growth. (Pradana and Wijaya, 2023) identified that in Indonesia, Economic Growth has fuelled the growth of the industrial sector, which contributed significantly to the increase in Carbon Emissions.

However, research by (Yoon and Kang, 2022) suggests that the impact of Economic Growth on Carbon Emissions can be minimized by strict environmental policies and incentives for green investments. For example, in the European Union, countries with strict environmental regulations managed to decouple the relationship between Economic Growth and Carbon Emissions through renewable energy subsidies and progressive carbon tax policies.

2.3. Renewable Energy Consumption

Renewable Energy Consumption has become a major focus of climate change mitigation efforts and the transition to sustainable energy systems to reduce dependence on fossil resources, which are major contributors to carbon emissions. According to (Schaefer et al., 2019), shifting to renewable energy in the energy and transport sectors has a positive impact on reducing the global carbon footprint. These sectors are major contributors to greenhouse gas emissions. The use of renewable energy reduces air pollution and improves environmental quality, which contributes to long-term climate change mitigation (Smith and Jones, 2021).

In developed countries, the renewable energy transition is driven by progressive policies, such as fiscal incentives for clean energy technologies, low-carbon infrastructure development, and regulations

that support energy efficiency (Franco et al., 2021). These policies help accelerate the adoption of renewable energy by reducing investment costs and speeding up the integration of new technologies in national energy systems. However, greater challenges are faced by developing countries, where barriers related to inadequate infrastructure, high initial costs, and reliance on cheaper fossil energy sources still hinder an effective transition (Duku et al., 2022).

According to Stern (2021), although developing countries have great potential for renewable energy, the lack of supportive policies and low investment in research and development of renewable technologies are major obstacles in accelerating this transition. Therefore, a number of studies emphasize the need for more progressive policies and careful planning to increase renewable energy capacity, and encourage greater investment in research and development to reduce carbon emissions in the energy and transport sectors (Chong et al., 2022). Renewable energy consumption continues to be seen as an effective solution in reducing carbon emissions and supporting sustainable economic growth. Strengthening supportive energy policies, improving infrastructure and developing more efficient technologies are key to accelerating the transition to a global low-carbon economy (Lee et al., 2021).

3. RESEARCH METHODOLOGY

3.1. Scope of Research

This study uses the Fully Modified Ordinary Least Squares (FMOLS) method as an econometric approach to analyze long-term relationships. The dependent variable in this study is Carbon Emission which is used as the main indicator of environmental impact. While the independent variables include Growth of the Transportation and Warehousing Sector and GDP as a measure of economic activity, and Renewable Energy Consumption as an emission mitigation factor. This study uses time series data from 2011 to 2023 which is analyzed using Eviews 10 software. The secondary data used is sourced from the World Bank.

The scope of this research not only focuses on testing the relationship between variables, but also aims to make a significant theoretical and empirical contribution to the literature on environmental economics. In the context of a developing country like Indonesia, this research provides an in-depth analysis of how the dynamics of the transportation and warehousing sector, economic growth, and the transition to renewable energy affect carbon emissions. This approach allows for the systematic identification of drivers and barriers to carbon emission reduction, providing a strong scientific basis for the formulation of low-carbon development policies and climate change mitigation strategies.

3.2. Classical Assumptions

The classical assumption test is a series of tests conducted to ensure that the regression model used fulfils the basic assumptions to obtain an unbiased, consistent and efficient estimation of the model parameters through normality and multicollinearity tests. The Fully Modified Ordinary Least Squares (FMOLS) method is designed to overcome some of the problems that arise in regression analysis of time series data that have cointegration properties. One of the main advantages of FMOLS is its ability to correct the problems of autocorrelation and heteroscedasticity in the residuals, which are two other classical assumptions in regression analysis (Pedroni, 2000).

3.3. Stationary Test (Unit Root Test)

The stationarity test is used to determine whether the data under study is stationary or not. For time series data, stationarity is a crucial requirement (Widarjono, 2018). Augmented Dickey-Fuller (ADF) testing can be used to detect whether the data is stationary or not by comparing the ADF statistical value to its critical value, namely the statistical distribution (Phillips and Perron, 2023). MacKinnon is a method used to evaluate whether or not data are stationary (MacKinnon, 2010). Data is said to be stationary if the absolute value of the ADF statistic exceeds its crucial value (Widarjono, 2018).

If the time series data is not stationary at zero order I(0) or level when tested by ADF testing, then the stationarity of the data can be sought with the following orders until it is stationary at the nth order, first difference or I(1), second difference or I(2), and so on (Enders, 2015). If the test findings reject the hypothesis that all variables have a unit root, it means that all variables are stationary at the level, or the variables are cointegrated at I(0), so linear regression is used for estimation (Gujarati and Porter, 2022).

The hypothesis of this test is:
H0 = 0, there is a unit root (not stationary)
Ha ≠ 0, there is no unit root (stationary)

If the test results reject the hypothesis that all variables have a unit root, it means that all variables are stationary at the level, or in other words, the variables are cointegrated at I(0), so linear regression is used for estimation.

3.4. Fully Modified OLS (FMOLS) Test

Fully Modified OLS (FMOLS) was introduced by Phillips and Hansen in 1990 to provide a robust estimation technique for time series data, especially when there is cointegration among the variables. This method corrects for autocorrelation and heteroscedasticity, which commonly arise in long-run economic models, thus ensuring unbiased and consistent parameter estimates.

The FMOLS model for this study can be formulated as follows:

$$Yt=\alpha+\beta1X1t+\beta2X2t+\epsilon t$$

Where:
Yt: Carbon Emission
X1t: Growth of the Transportation and Warehousing Sector
X2t: GDP
X3t: Renewable Energy Consumption
α: Intercept
$\beta1$ and $\beta2$: Coefficients of independent variables
ϵt: Error term

3.5. Statistical Test t (Partial Test)

In research, the significance of the influence of the independent variable on the dependent variable is seen through the t statistical

test (Widarjono, 2018). In its use, if t-count> t-table or significance is <(α) 5%, this indicates that there is a partially significant effect between the independent variable and the dependent variable (Gujarati, 2006).

The hypothesis in this test is:
H0: βi < 0 there is no significant effect between the independent variable and the dependent variable partially
Ha: βi > 0 there is a significant influence between the independent variables on the dependent variable partially

The test criteria are as follows:
1. If t-statistic > t-table then *H*0 is rejected. The independent variable has a significant effect on the dependent variable.
2. If t-statistic < t-table then *H*0 is accepted. The independent variable does not have a significant effect on the dependent variable.

3.6. F Statistical Test

The F-statistic test is used to show how the independent variables interact with each other and have an impact on the dependent variable (Wooldridge, 2013). If the F-count exceeds the F-table in the test, then simultaneously the independent variables have a considerable influence on the dependent variable, or the data are consistent with the research hypothesis.
H0: βi < 0 there is no significant effect between the independent variables on the dependent variable together.
Ha: βi > 0 there is a significant influence between the independent variables on the dependent variable jointly

The test criteria are as follows:
1. If F-statistic > F-table then *H*0 is rejected. The independent variable on the dependent variable has a statistically significant effect together.
2. If F-statistic < F-table then *H*0 is accepted. The independent variable on the dependent variable does not have a statistically significant effect together.

3.7. Test Coefficient of Determination (R^2)

According to Widarjono (2018), the coefficient of determination (R^2) is used to measure the proportion of the contribution of the independent variable in explaining the dependent variable. An R^2 value close to one indicates that the regression model has a good ability to explain data variability, while an R^2 value close to zero indicates limited ability. However, R^2 has the disadvantage that it tends to increase with the addition of independent variables, even though these variables do not necessarily increase the predictive power of the model. Therefore, adjusted R-square is used which corrects for the addition of irrelevant independent variables, so that the adjusted R-square value will not exceed R-square and may decrease or become negative if the addition of independent variables does not improve the quality of the model or if the model shows a low level of fit.

4. RESULTS

4.1. Classical Asumptions

Based on the normality test from the histogram in Figure 1, the probability value is 0.718331 > 0.05. Furthermore, the Jarque-Bera value < Chi-square value, which indicates that the data follows a normal distribution pattern.

Based on the results of the multicollinearity test presented in Table 1, it was found that none of the variables exhibited a correlation value exceeding 0.9. This indicates the absence of significant multicollinearity among the independent variables used in this study. In other words, the variables do not show a strong linear relationship or significant interdependence, ensuring the reliability of the regression model in isolating the effects of each independent variable.

4.2. Stationary Test (Unit Root Test)

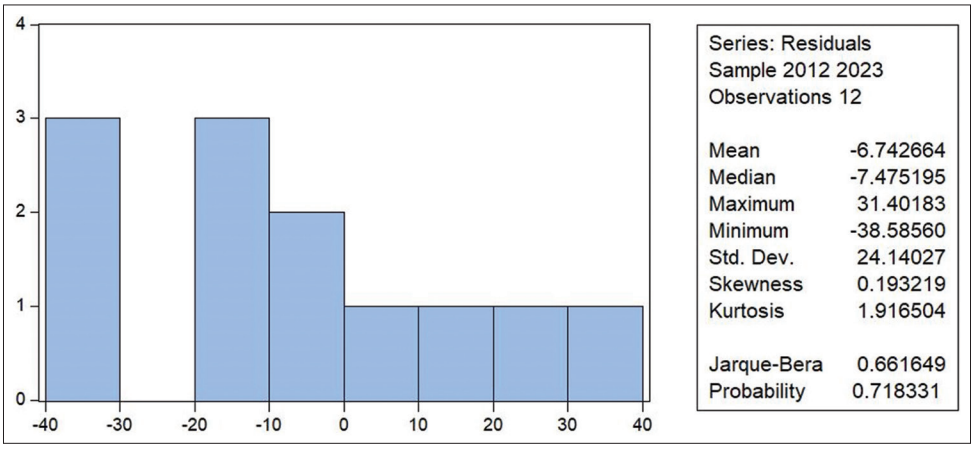
The results of the stationarity test using the Augmented Dickey-Fuller (ADF) method, as presented in Table 2, show that the

Table 1: Multicollinearity test

Correlation coefficient variable	(X1)	(X2)	(X3)
(X1)	1.000000	0.852150	0.325298
(X2)	0.852150	1.000000	0.486588
(X3)	0.325298	0.486588	1.000000

Source: Data analysis results, 2024

Figure 1: Normality test result



Source: Data analysis results, 2024

Table 2: Unit root test results at the second difference level

Variable	Probability	Description	Decision
D (X1,2)	0.0098	Stationary	Stationary at the Second Difference level"
D (X2,2)	0.0127	Stationary	
D (X3,2)	0.0000	Stationary	
D (Y,2)	0.0001	Stationary	

Source: Data analysis results, 2024

Table 3: Fully modified OLS (FMOLS) test results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
X1	11.59566	2.193536	5.286284	0.0007
X2	35.19515	8.725844	4.033438	0.0038
X3	−11.14587	2.671376	−4.172331	0.0031
C	940.9867	63.00278	14.93564	0.0000
R-squared	0.882221	Mean dependent var		569.8798
Adjusted R-squared	0.838053	S.D. dependent var		73.27302
S.E. of regression	29.48695	Sum squared resid		6955.842
Long-run variance	875.9774			

Source: Data analysis results, 2024
FMOLS: Fully modified ordinary least squares

Table 4: F statistical test results

Test statistic	Value	df	Probability
F-statistic	17.40665	(3, 8)	0.0007
Chi-square	52.21996	3	0.0000

Source: Data analysis results, 2024

variables Growth of the Transportation and Warehousing Sector (X1), GDP (X2), Renewable Energy Consumption (X3), and Carbon Emission (Y) have probability values less than the significance level of α = 5% (0.05). This indicates that all variables are stationary at the second difference level, meaning that the data meet the stationarity assumption required for further analysis..

4.3. Fully Modified OLS (FMOLS) Test

Fully Modified OLS (FMOLS) test results are presented in Table 4.

4.4. Statistical Test t (Partial Test)

The regression results presented in Table 3 can be interpreted as follows:

The coefficient of Growth of the Transportation and Warehousing Sector (X1) of 11.59566 indicates that every 1 unit increase in Growth of the Transportation and Warehousing Sector will increase Carbon Emission (Y) by 11.59566, assuming other variables remain constant. The t-statistic value is 5.286284 at 5% significance level, and the probability value (0.0007) is smaller than 0.05. Therefore, it can be concluded that Growth of the Transportation and Warehousing Sector has a positive and significant effect on Carbon Emission partially.

The coefficient of GDP (X2) of 35.19515 indicates that every 1 unit increase in GDP will increase Carbon Emission (Y) by 35.19515, assuming other variables remain constant. The t-statistic value is 4.033438 at the 5% significance level, and the probability value (0.0038) is smaller than 0.05. Therefore, it can be concluded that GDP has a positive and significant effect on Carbon Emission partially.

The Renewable Energy Consumption (X3) coefficient of −11.14587 indicates that every 1 unit increase in Renewable Energy Consumption will reduce Carbon Emission (Y) by 11.14587 assuming other variables remain constant. The t-statistic value is −4.172331 at 5% significance level, and the probability value (0.0031) is smaller than 0.05. Therefore, it can be concluded that Renewable Energy Consumption has a negative and significant effect on Carbon Emission partially.

4.5. F Statistical Test

Table 4 presents the results of the F-test, which evaluates the joint influence of independent variables on the dependent variable. In the long-term estimation, the probability value of the F-test is 0.0007, which is significant at the 5% level. This indicates that the Growth of the Transportation and Warehousing Sector (X1), GDP (X2), and Renewable Energy Consumption (X3) collectively have a significant impact on Carbon Emissions (Y). Furthermore, the F-test probability value of 0.0000, being less than the significance threshold of α = 5% (0.05), confirms that these independent variables, when analyzed simultaneously, exert a statistically significant effect on the dependent variable.

4.6. Results of the Coefficient of Determination (R2)

The coefficient of determination is used to measure how much variation in the dependent variable can be explained by variations in the independent variables. In this study, the coefficient of determination is carried out to determine how much the percentage of Growth of the Transportation and Warehousing Sector (X1), GDP (X2), Renewable Energy Consumption (X3) variables together or simultaneously have a significant effect on Carbon Emission (Y). Based on the results of the long-term analysis, the value of the coefficient of determination (R2) is 0.882221. This means that the influence of the variation of independent variables on the variation of the dependent variable is 82.22% while the remaining 17.78% is explained by variables outside the model.

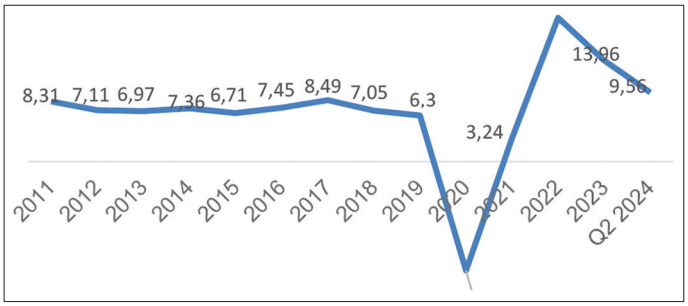
5. DISCUSSION

5.1. The Effect of Transportation and Warehousing Sector Growth on Carbon Emissions

Based on Figure 2, the Growth of the Transportation and Warehousing Sector demonstrates a significant relationship with carbon emissions, contributing greatly to global climate change. The sector's growth data from 2011 to the second quarter of 2024 reveals fluctuations reflecting Indonesia's economic dynamics, with stable growth between 6.38% and 8.31% annually before the COVID-19 pandemic. This stability implied increased fossil fuel consumption, particularly in land, sea, and air transportation. Such increases drove higher energy demands, contributing to greenhouse gas emissions and positioning this sector as a major contributor to climate change issues (Joo and Yoon, 2023). The sector's contraction in 2020, caused by activity restrictions during the pandemic, showed a significant reduction in carbon emissions. However, this positive impact was only temporary and linked to the sharp decline in economic activity (Sung and Park, 2022). Post-economic recovery in 2021-2022 saw significant growth of 19.87% in the sector, potentially increasing carbon emissions along with the surge in transportation and logistics demand (Chen and Zhang, 2022). Although growth in 2023 and the second quarter of 2024 slowed, transitioning to environmentally friendly technologies in the transportation sector remains imperative to curb long-term carbon emissions (Liu and Li, 2024). Therefore, despite the sector's fluctuating growth, efforts to reduce carbon emissions in the transportation and warehousing sector must be systematically pursued through policies supporting renewable energy use, electric vehicle development, and environmentally friendly infrastructure improvements to ensure the sector contributes to Indonesia's climate change mitigation goals.

The Growth of the Transportation and Warehousing Sector plays a crucial role in supporting national economic activities, with a significant contribution to Gross Domestic Product (GDP). In the post-COVID-19 pandemic period, this sector demonstrated rapid recovery, achieving growth of 19.87% in 2022 before slowing to 7.45% in Q2 2024. The sector's growth was driven by increased freight volume, extensive infrastructure development, and modern warehousing activities, which significantly impacted rising carbon emissions. This phenomenon occurred due to the dominance of fossil fuel usage, especially in land transportation, accounting for over 70% of logistics activities in Indonesia. The rise in logistics activity was also driven by the expansion of Special Economic Zones (SEZs), accelerating the distribution of goods between regions but not accompanied by innovations in low-carbon technology (Zhang and Liu, 2024).

Figure 2: Growth of the Transportation and Warehousing Sector (%)



Source: Statistics Indonesia, 2024

Key factors driving carbon emissions in this sector include the intensity of fossil fuel use, infrastructure efficiency, and the adoption rate of green technology. According to a report from the Coordinating Ministry for Economic Affairs, over 80% of commercial transport fleets in Indonesia still rely on diesel engines with low energy efficiency (Liu and Yang, 2023). This is exacerbated by uneven road infrastructure, leading to traffic congestion in metropolitan areas like Greater Jakarta (Hidayat and Wulandari, 2022). Traffic congestion results in significant additional carbon emissions, with estimates showing up to a 25% increase in urban areas compared to non-urban areas. Moreover, large-scale construction activities for national strategic projects, such as building 2,913 km of toll roads and operating new ports, temporarily increase carbon emissions due to the use of heavy machinery and high energy consumption during construction (Zhao and Li, 2023).

On the other hand, policies like the National Logistic Ecosystem (NLE), aimed at simplifying logistics processes and reducing goods distribution costs, have the potential to lower carbon emissions (Prasetyo and Mulyani, 2023). However, implementing these policies faces challenges such as the low adoption of digitalization by local logistics players and insufficient incentives for using low-carbon technology. The development of modern warehousing infrastructure, including cold storage facilities, can improve logistics efficiency but also contribute to carbon emissions through high electricity consumption, much of which still depends on coal-fired power plants (Sari and Surya, 2023).

Logistics management in Indonesia faces structural barriers, such as regional disparities in logistics infrastructure, reliance on land transportation, and weak regulations regarding energy efficiency (Tanjung and Alimuddin, 2023). For example, eastern Indonesia experiences logistics costs up to 2.5 times higher than western Indonesia, prompting additional emissions due to extended supply chains and greater fuel usage. Stronger mitigation strategies are needed, including integrating electric vehicles into logistics systems, implementing fiscal incentives for companies adopting green technologies, and strengthening emission regulation oversight through data-driven digital systems.

Overall, the analysis shows that the Growth of the Transportation and Warehousing Sector significantly increases carbon emissions due to structural and operational factors. Therefore, more integrated policies are needed, such as promoting the use of electric vehicles in logistics, providing fiscal incentives for low-carbon technologies, and developing data-driven emission monitoring systems (Setiawan and Tan, 2022). Investments in renewable energy for warehousing facilities should also be prioritized to reduce reliance on coal. If effectively implemented, these strategies can mitigate the environmental impact of the transportation and warehousing sector while ensuring sustainable national economic growth that supports the transition to a low-carbon economy and the achievement of net-zero emission targets by 2060.

5.2. Effect of GDP on Carbon Emission

Research findings reveal a positive correlation between economic growth and carbon emissions, consistent with the Environmental Kuznets Curve (EKC) hypothesis. In the early stages of economic development, growth tends to be accompanied by increased carbon emissions, driven by higher energy consumption during urbanization, industrialization, and infrastructure expansion. In developing countries like Indonesia, rapid economic growth from 2017 to 2022 significantly increased energy consumption in the transportation and industrial sectors, both of which heavily depend on fossil fuels. This aligns with the findings of Gunawan and Sulistyowati (2021), which highlight that reliance on fossil fuels exacerbates long-term carbon emissions, especially in developing nations undergoing rapid industrialization.

Conversely, developed countries with stable economic growth have demonstrated the capability to reduce carbon emissions through green technologies and stringent environmental policies. Peterson and Schmidt (2020) noted that European Union countries have managed to sustain economic growth without increasing carbon emissions by leveraging renewable energy sources and enforcing strict industrial emission regulations. However, developing nations face more complex challenges, including the high costs of green energy investments and insufficient environmental policies. In Indonesia, the adoption of renewable energy remains limited due to the substantial investments required, and existing regulations often fail to effectively promote broad energy transitions.

Grossman and Krueger (1995) suggest that at a certain income level, countries will begin adopting green technologies and improving energy efficiency, enabling reductions in carbon emissions. However, for developing nations, reaching this threshold may be challenging without international support in the form of investments in low-carbon technologies and subsidies for green energy. This indicates that while economic growth is crucial, strong energy transition policies are essential to mitigate the negative environmental impacts of growth.

5.3. Effect of Renewable Energy Consumption on Carbon Emission

Renewable energy consumption consistently exhibits a negative and significant relationship with carbon emissions, establishing it as a critical element in global climate change mitigation efforts. Renewable energy sources, including solar, wind, hydro, and bioenergy, offer low-carbon solutions with substantially reduced environmental impacts compared to fossil fuels, the primary drivers of carbon emissions. Global studies demonstrate that a 1% increase in renewable energy consumption can reduce carbon emissions by up to 0.8%, depending on the scale of technology adoption, efficiency, and supporting infrastructure (IEA, 2021). Countries with high renewable energy penetration, such as Norway and Iceland, have successfully reduced carbon emissions significantly while fostering sustainable economic growth (Kotsakis and Ioannou, 2022).

Indonesia possesses vast potential for expanding renewable energy consumption, particularly through geothermal, solar, and biomass resources. However, the utilization of these resources remains relatively low compared to their potential. According to the Ministry of Environment and Forestry, Indonesia's renewable energy potential exceeds 400 GW, encompassing 75 GW of hydropower, 207 GW of solar power, and 23 GW of geothermal energy. Yet, renewable energy consumption currently accounts for only about 14% of the targeted 23% contribution to the national energy mix by 2025. Indonesia's reliance on coal, which supplies over 60% of its national energy, hampers efforts to transition towards greater renewable energy adoption (IEA, 2021).

The transition to renewable energy faces significant obstacles, including high initial investment costs, insufficient infrastructure, and resistance from industries reliant on fossil fuels (Jusuf and Rahim, 2022). For instance, while the government has introduced various incentives, such as feed-in tariffs and tax reductions, renewable energy adoption is often hindered by complex licensing procedures and inadequate infrastructure to effectively deploy renewable energy, especially in remote areas.

This phenomenon underscores the importance of integrated policies to promote investments in renewable energy consumption. Studies from countries like Germany and Denmark reveal that combining fiscal incentives, direct subsidies for renewable energy investments, and strengthening domestic technological capacity plays a crucial role in accelerating the clean energy transition (Wagner and Meyer, 2020). In Indonesia, reallocating fossil fuel subsidies to renewable energy investments and enhancing clean energy infrastructure across the archipelago can expedite renewable energy adoption. Additionally, raising public and industrial awareness of the economic and environmental benefits of this transition is vital to building collective momentum towards renewable energy (IRENA, 2021).

The effectiveness of increasing renewable energy consumption in reducing carbon emissions relies not only on adopting new technologies but also on improving energy efficiency, particularly in the industrial and transportation sectors, which are major contributors to Indonesia's carbon emissions (Wahyudi et al., 2024). Data indicates that these sectors account for nearly 60% of the country's total carbon emissions (KLHK, 2023). Policies promoting energy efficiency, such as adopting low-carbon technologies and renewable energy-based vehicles, are crucial for reducing emissions (Andrian et al., 2024). Furthermore, strengthening the National Energy General Plan (RUEN) and aligning it with Indonesia's Nationally Determined Contributions (NDC) target of a 29% emissions reduction by 2030 provide a robust framework for promoting renewable energy consumption as part of the nation's decarbonization strategy (UNFCCC, 2022).

6. CONCLUSION

This study makes a significant contribution to the environmental economics literature by uncovering the dynamics between the growth of the transportation and warehousing sector, Gross Domestic Product (GDP), and renewable energy consumption in relation to carbon emissions in Indonesia. The key findings reveal that the rapid growth of the transportation and warehousing sector, driven by urbanization and increased logistics activities, plays a pivotal role in escalating carbon emissions, with fossil

fuel dependency as the primary driver of energy consumption and pollution. GDP exhibits a similar trend, where economic activity in its initial stages amplifies carbon emissions, consistent with the Environmental Kuznets Curve (EKC) theory. In contrast, renewable energy consumption demonstrates a mitigative effect on carbon emissions, indicating that adopting clean energy sources can reduce fossil fuel dependence and lower the carbon footprint in key sectors. These findings underscore the urgency of implementing policies that support green technology adoption and renewable energy utilization, as well as enhancing energy efficiency in the transportation and warehousing sectors, as primary strategies for addressing climate change.

REFERENCES

Abdelrahman, M., Ahmed, S., Khalid, A. (2022), Energy optimization in logistics warehousing: A renewable approach. Energy Policy, 156, 112-120.

Andrian, T., Wahyudi, H., Leny, SM. (2024), Strategies to achieve net zero emissions 2060 with CSR disclosure. International Journal of Energy Economics and Policy, 4(6), 574-579.

Arouri, M., Ben Youssef, A., M'henni, H., Rault, C. (2022), Energy consumption, economic growth, and CO_2 emissions in Middle Eastern and North African countries. Energy Policy, 45(1), 342-349.

Chen, S., Fang, D., Zhou, Y. (2021), Environmental Kuznets curve hypothesis and carbon reduction policies in developed countries. Environmental Economics and Policy Studies, 25(2), 159-173.

Chen, W., Zhang, X. (2022), Economic growth and carbon emissions in developing countries: The role of sectoral shifts. Environmental and Resource Economics, 74(2), 431-449.

Chong, L., Tan, M., Wang, J. (2022), Overcoming barriers in renewable energy transition in developing countries: A policy and investment framework. Renewable Energy Review, 45(7), 1120-1135.

Dinda, S. (2022), Environmental Kuznets curve and the relationship between economic growth and carbon emissions in the EU. Environmental Economics and Policy Studies, 24(4), 557-568.

Duku, M., Johnson, K., Abena, T. (2022), Barriers to renewable energy adoption in developing economies: A review of key challenges. Energy Policy, 160, 112-122.

Enders, W. (2015), Applied Econometric Time Series. Hoboken, NJ: Wiley.

Forster, P.M., Storelvmo, T., Armour, K., Tett, S.F.B., Boucher, O., Jones, C., Kharin, V. (2023), The role of greenhouse gas emissions in climate change mitigation. Environmental Research Letters, 18(12), 124004.

Franco, M., Arango, S., Dey, C., Kumar, S., Torres, A. (2021), Policy and technological pathways for renewable energy transition in developed economies. Renewable Energy, 169, 290-302.

González, A., González, P., Sancho, F. (2022), Transport sector and carbon emissions: Analyzing global trends. Transport Policy, 117, 88-97.

Grossman, G.M., Krueger, A.B. (1995), Economic growth and the environment. The Quarterly Journal of Economics, 110(2), 353-377.

Gujarati, D.N. (2006). Essentials of Econometrics. 3rd ed. New York: McGraw-Hill.

Gujarati, D.N., Porter, D.C. (2022), Basic Econometrics. New York: McGraw-Hill Education.

Gunawan, T., Sulistyowati, D. (2021), The impact of fossil fuel dependency on carbon emissions during economic growth in developing countries: The case of Indonesia. Journal of Environmental Economics and Development Studies, 7(2), 123-135.

Haque, M.M., Ali, M.A., Siddique, M.M. (2023), Structural challenges for low-carbon transition in developing economies: A case study of Indonesia. Environmental Research Letters, 18(2), 215-230.

Hidayat, F., Wulandari, D. (2022), Urban traffic congestion and its impact on carbon emissions in metropolitan areas: Evidence from Jakarta. Transportation Research Part A: Policy and Practice, 150, 61-73.

International Energy Agency (IEA). (2021), Renewable Energy Market Update: Outlook for 2021 and 2022. International Energy Agency. Available from: https://www.iea.org/reports/renewable-energy-market-update-2021

International Renewable Energy Agency (IRENA). (2021), Promoting Renewable Energy Investment: A Guide for Policy Makers. IRENA. Available from: https://www.irena.org

Joo, J., Yoon, H. (2023), The relationship between transportation sector growth and carbon emissions in developing economies. Environmental Economics and Policy Studies, 25(1), 45-63.

Jusuf, H., Rahim, M. (2022), Challenges in renewable energy development in Indonesia: Infrastructure and investment barriers. Journal of Renewable Energy Development, 10(3), 145-159.

KLHK. (2023), Renewable Energy Status Report 2023. Kementerian Lingkungan Hidup dan Kehutanan RI. Available from: https://klhk.go.id/report-renewable-energy-2023

Kotsakis, C., Ioannou, A. (2022), The role of renewable energy in mitigating carbon emissions: A comparative analysis of Nordic countries. Energy Policy, 157, 112461.

Lee, R., Martinez, A., Khan, H. (2021), Enhancing the efficiency of renewable energy systems in developing nations: Key challenges and opportunities. Renewable and Sustainable Energy Reviews, 138, 110615.

Liu, J., Li, H. (2024), Renewable energy consumption and its impact on carbon emissions: Evidence from Southeast Asia. Renewable and Sustainable Energy Reviews, 163, 112458.

Liu, X., Yang, L. (2023), The role of fuel efficiency and energy consumption in reducing transportation sector emissions: A case study in Indonesia. Environmental Science and Policy, 127, 105-117.

MacKinnon, J.G. (2010), Critical values for cointegration tests. In: Handbook of Econometrics. Vol. 4. Amsterdam: North-Holland. p267-289.

Mulyani, S., Widodo, T. (2023), The impact of urbanization and E-commerce growth on carbon emissions in Indonesia. Sustainability Science, 28(3), 233-245.

Nordhaus, W.D. (2021), Climate change: The effects of energy policy. Environmental Economics and Policy Studies, 23(3), 253-269.

Nugroho, A., Suryani, R., Hadi, S. (2023), Energy transition in Indonesia: Barriers and opportunities for renewable energy adoption. Renewable Energy, 163, 2332-2343.

Pedroni, P. (2000), Fully modified OLS for heterogeneous cointegrated panels. Advances in Econometrics, 15, 93-130.

Peterson, R., Schmidt, F. (2020), Green Technology and Emission Reduction: Evidence from the European Union. Environmental Economics and Policy Studies, 22(2), 217-245.

Phillips, P.C.B., Perron, P. (2023), Testing for a unit root in time series regression. Econometric Reviews, 41(2), 215-229.

Pradana, A., Wijaya, S. (2023), Industrial expansion and carbon emissions in Indonesia: A case study on economic growth impacts. Asian Journal of Environmental Research, 15(3), 421-435.

Prasetyo, E., Mulyani, A. (2023), National Logistic Ecosystem (NLE) and its potential impact on carbon emissions reduction in Indonesia's logistics sector. Sustainability, 15(4), 1015.

Sari, R., Surya, M. (2023), The impact of modern warehousing infrastructure on logistics efficiency and carbon emissions in Indonesia. Renewable and Sustainable Energy Reviews, 156, 111998.

Schaefer, C., Droege, S., Helbig, M., Klepper, G. (2019), The role of renewable energy in climate change mitigation: Challenges and opportunities. Renewable and Sustainable Energy Reviews, 101, 125-138.

Setiawan, A., Tan, W. (2022), Green logistics and fiscal incentives: A policy approach for reducing carbon emissions in Indonesia's transport sector. Journal of Cleaner Production, 316, 128313.

Setiawan, Y., Mahendrawati, M. (2023), Impact of Transportation growth on carbon emissions in Indonesia: A Sectoral Analysis. Energy Policy, 168, 112-121.

Smith, J., Jones, A. (2021), Renewable energy as a pathway to sustainable development: Impacts on carbon emissions and environmental quality. Energy Policy, 143, 230-245.

Stern, N. (2021), The role of renewable energy in sustainable economic development: A global perspective. Energy Economics, 97, 135-148.

Sung, Y., Park, S. (2022), COVID-19 and the environment: The temporary decline in carbon emissions and the post-pandemic rebound. Climate Policy, 22(4), 467-481.

Tanjung, F., Alimuddin, M. (2023), Regional disparities in logistics cost and its impact on carbon emissions in Indonesia. Asian Economic Policy Review, 18(2), 248-264.

UNFCCC. (2022), Indonesia's Updated NDC 2022. United Nations Framework Convention on Climate Change. Available from: https://unfccc.int/documents/indonesia-ndc-2022

Wagner, R., Meyer, P. (2020), Renewable energy policies in Germany and Denmark: Lessons for developing economies. Energy Policy, 143, 111571.

Wahyudi, H., Leny, SM., Sutarto. (2024), CSR index of energy sector companies in Indonesia. International Journal of Energy Economics and Policy, 14(6), 40-45.

Wang, L., Zhang, C., Lee, H. (2022), The role of the transportation sector in carbon emissions: Evidence from Southeast Asia. Environmental Economics and Policy Studies, 24(2), 185-198.

Widarjono, A. (2018), Econometrics: Theory and Applications. Yogyakarta: UPP STIM YKPN.

Wooldridge, J.M. (2013), Introductory Econometrics: A Modern Approach. 5th ed. United States: Cengage Learning.

Yoon, J., Kang, S. (2022), Economic growth, strict environmental policies, and decoupling of carbon emissions in the European Union. Journal of Environmental Policy and Planning, 24(2), 321-340.

Zhang, X., Liu, W. (2024), Economic zones and carbon emissions: The impact of infrastructure expansion and logistics development. Journal of Economic Development and Environmental Sustainability, 10(2), 112-130.

Zhao, Y., Li, Q. (2023), The environmental impact of large-scale infrastructure projects: Emission analysis in construction and transport sectors. Journal of Environmental Management, 300, 113692.