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THE ROLE OF ENERGY TRANSITION AND INTENSITY ON CO2 IN OECD COUNTRIES

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Abstract
The purpose of this study was to analyze the influence of GDP per capita, renewable energy consumption, and energy intensity on CO2 emissions in 38 OECD member countries during the period 2010–2022.This study uses a quantitative approach and panel data regression The results of this study found that all independent variables have a significant influence on CO2 emissions. GDP per capita and energy intensity have a positive effect, with elasticities of 0.060% and 0.67%, respectively, indicating that economic growth and energy inefficiency increase emissions. In contrast, renewable energy consumption had a negative effect with an elasticity of -0.016%, confirming the important role of clean energy in reducing emissions. These findings are in line with the Environmental Kuznets Curve (EKC) hypothesis and emphasize the urgency of the energy transition and improving energy efficiency in developed countries.

Keywords: CO2 Emissions, GDP Per Capita, Renewable Energy Consumption, Energy Intensity, Environmental Kuznets Curve

1. Introduction

Sustainable development and the Sustainable Development Goals (SDGs) have become a global agenda since the adoption of the 2030 Agenda by the United Nations in 2015. The European Commission affirmed that the SDGs must be inter integrated, recognizing that alleviating poverty and inequality must be accompanied by improved health, education and economic growth all while tackling climate change and protecting the environment (OECD, 2024). The EU has even included the principle of sustainable development as a core in the EU Treaty and its internal-external policies (OECD, 2024). Similarly, the OECD states that 17 SDGs goals are universal with the mission “Improving Life” and “Protecting the planet”. Although these initiatives demonstrate the high commitment of Europe and OECD countries, the report OECD (2022) warned that many countries are still lagging behind in achieving social and environmental targets.

However, the development of human economic development also causes negative externalities, especially in the form of carbon emissions and environmental pollution. Industrial, transportation, and fossil energy activities produce greenhouse gases that damage the global climate as well as air pollution that threatens public health. According to the European Environment Agency (EEA), air pollution and heat waves due to climate change account for about 13% of total deaths in Europe. In fact, it is estimated that more than 400,000 people die prematurely every year in Europe due to air pollution (Abnett, 2020).

It is this concern over climate externalities that drives international climate agreements. The Kyoto Protocol (1997) was the first international agreement that bound developed countries to cut GHG emissions. After the first period of Kyoto ended, COP15 Copenhagen 2009 sought to formulate its successor. Although not legally binding, the Copenhagen Accord confirms the goal of limiting global warming to below 2°C and

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contains regional commitments, for example the European Union states it will reduce emissions by at least 20% from 1990 levels by 2020 (which can be increased to 30% if other developed countries also commit). Negotiations continued until the Paris Agreement was finally reached at COP21 in 2015. The Paris Agreement was quickly signed and ratified by almost all UNFCCC countries (195 participating countries plus the European Union), making it a legally binding universal climate agreement. The Paris Agreement replaces the Kyoto/Copenhagen framework with a national contribution mechanism (Nationally Determined Contributions, NDC) for each country and commits to making global temperature rise "well below 2°C".

Although the Paris Agreement has been implemented as a global guide to tackling climate change, the reality is that Europe is still experiencing extreme weather that is very worrying. The summer of 2022 was recorded as the hottest in the history of the continent, with temperatures exceeding previous records. Research by Ballester et al (2023) published in Nature Medicine shows that from May 30 to September 4, 2022, there were around 61,672 deaths caused by heat waves in 35 countries in Europe. Not only that, in the summer of 2023, Europe is again facing an extreme heat wave called Cerberus. This heat wave caused temperatures to exceed 45°C in some countries such as Italy, Spain and Greece, which triggered massive forest fires and caused problems for public health. In 2023, it is estimated that there will be around 47,690 heat-related deaths in Europe, making it the year with the second-highest number of heat-related deaths since 2015 (Gallo et al., 2024).

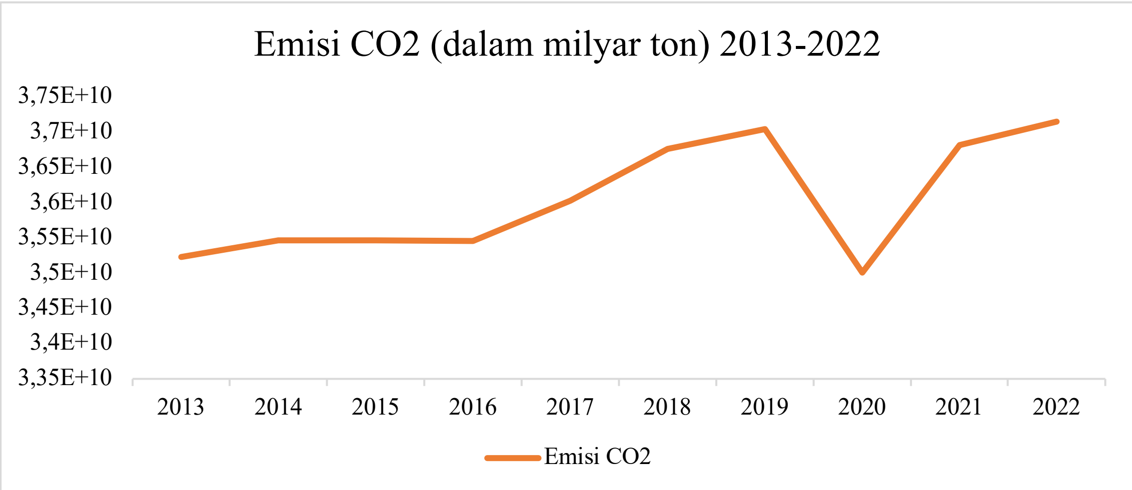

Figure 1. Total Global CO2 Emissions 2013-2022
Source: World Bank

The extreme weather events represented by the Cerberus heat wave show that the increase in carbon emissions as a major factor in global warming continues to affect the strength and frequency of extreme temperatures, so it is important to analyze the development of total global CO2 emissions. Based on the figures showing total global CO2 emissions, it can be seen that between 2013 and 2016, CO2 emissions were relatively stable, with figures varying from 35.2 to 35.4 billion tons per year. This describes a state in which industrial activity and global energy consumption are taking place quite constantly. However, since 2017, CO2 emissions have begun to increase significantly. In that year, emissions reached 36 billion tons and continued to increase until reaching a peak in 2019, amounting to 37 billion tons. This increase can be attributed to the growth of global economic activity and higher energy consumption, which is driving the use of fossil fuels, particularly in the industrial and transportation sectors.

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Things changed drastically in 2020. CO2 emissions decreased significantly to 35 billion tonnes, the highest decline in the last ten years. This is due to the COVID-19 pandemic that has hit the whole world. Closures, shutdowns of industrial activities, travel restrictions, and global economic downturn have led to tremendous reductions in carbon emissions, having a major impact on energy consumption patterns in many countries.

After that sharp decline, 2021 and 2022 saw an increase in CO2 emissions in line with the global economic recovery. In 2021, emissions rose again to 36.8 billion tons, while in 2022 it reached the highest figure in a decade, at 37.1 billion tons. This shows that after a temporary decline due to the pandemic, economic, transportation, and industrial activities are back to operating near full capacity, thus encouraging CO2 emissions to increase again. Overall, the period 2013 to 2022 shows a pattern in which CO2 emissions continue to increase, with temporary variations caused by external factors such as the pandemic.

These real conditions cast doubt on the effectiveness of the Paris Agreement in practice. Report from The Climate Action Monitor 2024 (2024) shows that current targets and policies are still far from enough to report that the combined NDCs of major countries are only targeting a collective emission reduction of 14% by 2030 compared to 2022 levels, far below the 43% needed to meet the 1.5°C target according to the IPCC. While 110 countries have pledged net-zero by 2050, only 27 countries plus the European Union (about 16% of global emissions) have enshrined the pledge in legal form (OECDs, 2024). Our World in Data also estimates that current policies only prevent global warming by around 2.7°C (well above the Paris target) (Ritchie et al., 2023). Important questions arise to what extent these climate agreements actually disrupt emissions trends in OECD countries, and what steps are needed to bridge the remaining ambition gap (The Climate Action Monitor 2023, 2023).

2. Theoretical Background

2.1 Environmental Kuznet Curve

One method to understand and assess environmental damage and economic development in an area is to utilize the Environmental Kuznets Curve Hypothesis (EKC). In 1991, Grossman and Krueger developed the concept of the Environmental Kuznets Curve (EKC) to evaluate the relationship between economic growth and environmental conditions. This hypothesis states that when a country's income is low, the government will focus on increasing economic growth through investment and production, which, while ignoring environmental issues, will contribute to increased income. At this stage, the level of pollution will increase as income increases, and then will decline again as income grows continuously. This theory emphasizes the importance of government regulation in improving environmental quality and improving people's welfare, which in turn will encourage social control (Mason & Swanson, 2002). The EKC hypothesis suggests that while economic development can increase emissions, it can also reduce the level of environmental pollution (Grossman & Krueger, 1991).

In line with Kuznets' Environmental Curve theory, one of the main indicators that is often studied in looking at the relationship between economic activity and environmental degradation is Gross Domestic Product (GDP) per capita. According to the EKC hypothesis, in the early stages of economic growth, an increase in GDP per capita tends to be positively correlated with an increase in carbon emissions due to industrial expansion and fossil-based energy consumption. However, after reaching a certain level of income, known as the turning point, countries began to shift the focus to environmental

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issues and improve energy efficiency as well as investment in clean technologies. Based on previous studies by Ochi & Saidi (2024). The variable GDP per capita has a positive impact on carbon dioxide emissions. This is in line with the findings Nadeak & Nasrudin (2023) which shows that in both the long and short term, GDP per capita has a positive and significant effect on CO2 emissions. However, other research by Methmini et al (2025) found that GDP per capita is negatively related to carbon dioxide emissions. These findings support the Environmental Kuznets Curve hypothesis, which states that increased income levels can reduce environmental degradation. The Environmental Kuznets Curve (EKC) describes the relationship between GDP per capita and carbon emissions in an inverted U-curve pattern. At the beginning of the economic growth phase, an increase in GDP per capita is often accompanied by an increase in carbon emissions. This is due to industrialization, increasing consumption of fossil energy, and the use of technology that is still less efficient.

However, GDP per capita alone does not adequately explain the dynamics of carbon emissions. Therefore, it is also necessary to consider other variables that reflect changes in energy policy and environmentally friendly technological innovation. One of these important variables is the consumption of renewable energy. In the context of EKC, renewable energy consumption reflects efforts to transition to cleaner energy sources as incomes and environmental awareness increase. Based on previous studies, Huylo et al (2025) revealed that the use of energy from renewable sources can reduce emissions by up to 45.4%. This indicates a significant negative impact on changes in carbon dioxide emissions. These findings are also reinforced by research Tsandra et al (2023) and Justice et al (2024) which shows that the use of renewable energy contributes to the reduction of carbon emissions. This suggests that increased use of energy from renewable sources will reduce carbon dioxide emissions in industrially developing countries.

In addition, energy intensity, which measures the efficiency of energy use to economic output, is also an important proxy in assessing the technological transition towards low-carbon development. The lower the energy intensity, the more efficient a country is at harnessing energy to generate economic value, ultimately leading to a reduction in emissions. According to research conducted Marra et al (2024), the level of energy use has a positive effect. Efficient use of energy can lower emissions and encourage changes in technology or structure. Research from Du et al (2024) and Wei & Lahiri (2022) This statement supports this statement by showing that the use of energy plays a role in reducing carbon emissions as well as being an important indicator for carbon emission control in the manufacturing industry. As energy consumption per unit of GDP increases (which means energy efficiency decreases), the level of CO2 emissions will also increase, and vice versa.

2.2 Literature Review

Table 1. Literature Review

Yes	Name and Year	Country	Method	Result
1	Ahmad et al (2024)	Indonesia	Error Correction Model	GDP per capita has a positive and significant effect on Indonesia, both in the short and long term.
2	Methmini et al (2025)	28 countries in the Americas	Multiple Linear Regression Model	GDP has a positive impact.

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3	Ochi & Saidi (2024)	33 countries with the highest pollution in terms of greenhouse gas emissions	Panel Vector Autoregressive Model	Economic growth has a positive and significant influence
4	Huylo et al (2025)	Texas	Reduced Order Model	Renewables can reduce emissions by up to 45.4%.
5	Justice et al (2024)	Ghana	Mediation Model	Renewable energy has a negative effect on CO 2 emissions
6	Jiang et al (2024)	G7 countries	Cross-sectional autoregressive distributed lag	Renewable energy has a negative effect on emissions
7	Du et al (2024)	China	Robustness Tests	Energy intensity affects emissions
8	Wei & Lahiri (2022)	99 countries	Panel Data Regression	Energy intensity affects emissions.

3. Methods

This study is a descriptive study with a quantitative approach, which aims to describe or explain the characteristics of a phenomenon or population through the use of quantitative data. For this study, the data used is secondary data obtained from the World Bank, Our World in Data and the International Energy Agency. There are three independent variables, namely GDP Per Capita, Renewable Energy Consumption, and Energy Intensity, while the bound variable in this study is CO2 Emissions. This study uses panel data with a focus covering 38 OECD member countries, in a cross-section and time series, with a time period analyzed for 13 years, from 2010 to 2022. The analysis tool used was Eviews 13 with the panel data regression method.

3.1 Operational Definition

Table 2. Operational Definition

Yes	Variable	Definition and Size	Unit	Symbol	Source
1	Carbon Dioxide Emissions	Annual emissions of carbon dioxide (CO2), one of Kyoto's six greenhouse gases (GHGs), from the agriculture, energy, waste, and industrial sectors, excluding LULUCF.	Ton	CO2	World Bank
2	GDP Per Capita	GDP per capita is the gross domestic product (GDP) divided by the total population in the middle of the year.	U.S. Dollar	GDPP	World Bank
3	Renewable Energy Consumption	The percentage of renewable energy consumption is a measure that shows the proportion of energy derived from renewable natural resources compared to the total final energy consumption	Percentag e	REC	World Bank, Our World in Data, Internat ional Energy Agency
4	Energy Intensity	The energy intensity level of primary energy is the ratio between energy supply and gross domestic product measured by purchasing power parity. .	Ratio	EI	World Bank

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Furthermore, based on what has been explained, the panel data regression model in this study is formed as follows:

$$LNCO2_{it} = \beta 0 + \beta 1\ LNGDPP_{it} + \beta 2\ REC_{it} + \beta 3\ EI_{it} + \mu it$$

Where CO2 is carbon dioxide emission as a bound variable. GDPP is GDP Per Capita, REC is Renewable Energy Consumption and EI is Energy Intensity, all three are independent variables. While LN is a Natural Logarithm.

4. Results and Discussion

The selection of the panel data method estimation is determined by several tests. The Chow test to determine the selected model is Common Effect Model or Fixed Effect Model, the Hausman Test is to determine the selected model Fixed Effect Model or Random Effect Model, and the Lagrange Multiplier (LM) test is to determine the selected model Random Effect Model or Common Effect Model.

4.1 Chow Test

Table 3. Chow Test

Effects Test	Statistics	D.F.	Prob.
Cross-section F	5389.341161	-37,453	0.000
Cross-section Chi-square	3008.199852	37	0.000

Source: Data Processing Results Eviews 13, 2025

If the probability value < 0.05, then the most appropriate model to use is FEM. It is known that the probability value in the chow test is < 0.05, meaning that the right model to use is FEM. Next, we will perform a thirst test to choose the most appropriate model FEM or REM.

4.2 Hausman Test

Table 4. Hausman Test

Test Summary	Chi-Sq. Statistics	Chi-Sq. D.F.	Prob.
Cross-section random	5.908637	3	0.1161

Source: Data Processing Results Eviews 13, 2025

If the probability value < 0.05, then the most appropriate model to use is FEM. Based on the results of the thirst test, a probability value of > 0.05 was obtained, meaning that REM was more appropriate to use than FEM.

4.3 Lagrange Multiplier Test

Table 5. Lagrange Multiplier Test

	Test Hypothesis Cross-section	Time	Both
Breusch-Pagan	2936.509	6.479	2942.988
	0.000	0.011	0.000

Source: Data Processing Results Eviews 13, 2025

Then we do the last model selection test, namely the LM Test. If the probability value < 0.05, then the most appropriate model to use is FEM. In the above results, it is known that the probability of Breusch-Pagan cross-section is obtained < 0.05, so the final model chosen is REM.

4.4 Classic Assumption Test

The results of the normality test showed a probability value of 0.056415 > 0.05, meaning that the residual was distributed normally. The multicollinearity test showed that

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the correlation between the free variables did not exceed 0.8, so it was concluded that the data passed the multicollinearity test. Furthermore, in the heteroscedasticity test, the total probability value of the free variable is more than 0.05, meaning that the data is free from heteroscedasticity problems. In addition, the selection of the REM model which is the whose calculation uses the GLS method (Generalized Least-square) can accommodate autocorrelation problems in the model (Gujarati & Porter, 2009)

4.5 Regression Results

Table 6. Regression Results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
GDPP	0.060561	0.028143	2.151926	0.0319
REC	-0.016026	0.001195	-13.40818	0.0000
INTENSITY	0.067223	0.010001	6.721317	0.0000
C	17.79666	0.387187	45.96402	0.0000
Effects Specification				
			S.D.	Rho
Cross-section random			1.411349	0.9978
Idiosyncratic random			0.066521	0.0022
Weighted Statistics				
R-squared	0.508207	Mean dependent var		0.239413
Adjusted R-squared	0.505196	S.D. dependent var		0.094848
S.E. of regression	0.066718	Sum squared resid		2.181164
F-statistic	168.7845	Durbin-Watson stat		0.506232
Prob(F-statistic)	0.0000			

Source: Data Processing Results Eviews 13, 2025

Based on the regression results from the processing of eviews data above, the following equation model can be concluded:

$$LNCO2_{it} = 17.79666 + 0.060561\ LNGDPP_{it} - 0.016026\ REC_{it} + 0.067223\ EI_{it} + \mu it$$

4.6 T test

Table 7. T test

Independent Variables	Bound Variable (Y) = CO2			
	T-Statistics	T-Table	Probability	Conclusion
GDDP	2.151926	1.965	0.0319	Influential
REC	-13.40818	1.965	0.0000	Influential
EI	6.721317	1.965	0.0000	Influential

Source: Data Processing Results Eviews 13, 2025

The t-test aims to see if independent variables have a partially significant influence on bound variables. The results show that all partially independent variables have a probability value of < 0.05, meaning that both GDP per capita, renewable energy consumption and energy intensity, all three have a significant effect on CO2 carbon emissions.

4.7 Test F

Table 8. Test F

DF1	DF2	a	F-Table	F-stat	Probability	Conclusion
3	494	0.05	2.623	168.7845	0.0000	Influential

Source: Data Processing Results Eviews 13, 2025

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The F test is useful to find out whether all the independent variables in the model have a combined influence on the bound variables. Based on the table of results of the F test above, a probability value of < 0.05 was obtained. Therefore, it can be concluded that all independent variables, namely GDP per capita, renewable energy consumption and energy intensity, together have a significant effect on CO2.

4.8 Coefficient of Determination

The value of the determination coefficient (R2) is 0.508207. While the remaining value of 0.491793 can be explained by other variables that are not included in the model. In other words, changes in bound variables can be explained by an independent variable of 51% and the remaining 49% can be explained or influenced by other variables.

4.9 Discussion of Independent Variables

4.9.1 Effect of GDP Per Capita on Carbon Dioxide Emissions

Based on the results of the regression of the GDP per capita variable, the results show that GDP per capita has a positive and significant effect on carbon dioxide emissions. The value of the coefficient in the variable GDP per capita is 0.060561, indicating that when GDP per capita increases by 1%, it will increase carbon dioxide emissions by 0.060%, cateris paribus. In terms of this positive influence, this is in line with the research conducted by Yunita et al (2023) shows an increase in GDP per capita can increase energy consumption and industrial production which will ultimately contribute to an increase in CO2 emissions. Increased production and energy consumption will increase the use of fossil fuels which are the main source of CO2 emissions. These results are also supported by Ahmad et al (2024) which explains that in the short and long term GDP per capita has a positive effect on CO2 emissions. Efforts to increase GDP require economic activities such as consumption and production. The GDP that continues to increase shows that people's purchasing power is getting bigger. The higher the consumption, the higher the production in industries that require the use of fossil energy. This triggers CO2 emissions. So, it can be concluded that an increase in GDP per capita leads to an increase in CO2 emissions through increased consumption of fossil energy and industrial activities.

The positive relationship between GDP per capita and CO2 emissions can be explained by the Environmental Kuznets Curve (EKC) theory. In the early and intermediate stages of economic growth, the scale effect dominates, every increase in economic output (GDP) is almost always accompanied by an increase in energy consumption, especially fossil fuels, so that total CO2 emissions also increase. Only after revenues reach a certain threshold do the composition effect (shift from heavy industry to services) and technique effect (adoption of clean technology and stricter regulations) begin to offset and then lower emissions, forming an inverted-U-pattern typical of EKC. On the other hand, empirically, according to data sourced from Our World In Data, CO2 Emissions per Capita vs. GDP per Capita (2024), many OECD countries are still dwelling on the upward right side of the EKC curve, which is before the turning point. For example, Our World in Data data shows that in the range of GDP per capita between USD 30000-80000, most OECD countries still have CO2 emissions between 5-20 tons per capita with a relatively positive slope. Similarly, reports OECD (2020) stated that the average CO2 emissions of the OECD region were around 9 tons per capita in 2018, much higher than the world average (4 tons), confirming that emission reductions have not been consistent at this income level.

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4.9.2 The effect of renewable energy consumption on carbon dioxide emissions

Renewable energy consumption has a negative and significant regression result with a coefficient value of -0.016026. This means that if renewable energy consumption increases by 1%, it will affect a decrease in carbon dioxide emissions by 0.016%, cateris paribus. This is in line with research conducted by Jiang et al (2024), where renewable energy significantly lowers CO2 emissions, thereby promoting carbon neutrality. Renewable energy is important in the short and long term. An increase in the percentage of renewable energy resources will result in a proportionate reduction in CO2 emissions. This is also supported by research from Justice et al (2024) where in his study, he argued that renewable energy has a negative and significant impact on CO2 emissions. The use of renewable energy can help reduce carbon emissions to improve environmental sustainability. This shows that the increase in renewable energy helps reduce environmental stress. In addition, the development of renewable energy helps curb carbon emissions.

The negative and significant relationship between renewable energy consumption and CO2 emissions can be explained through the energy sector substitution and decarbonization mechanisms. Renewable energies such as wind, solar, biomass, and hydro power have almost zero emission intensities, so any increase in their use directly replaces the generation of electricity from high-emission fossil fuels. In addition, increased investment in storage technology and smart grids adds flexibility to the electricity system, so that renewable energy can be better absorbed and reduces the need for fossil fuel-based reserves (Perone, 2024).

In the OECD region, based on World Bank data (2023) Renewable energy consumption also shows a strong trend towards increasing share in the energy mix. According to the latest data, the average consumption of renewable energy in total final energy consumption of OECD countries increased from around 10% in the early 2010s to more than 12% in 2023. Meanwhile, 52% of electricity generated in the OECD by 2024 will come from clean sources (including renewables and nuclear), exceeding the global average of 41% (Ember Energy, 2025). This achievement is driven by ambitious policies such as national renewable energy targets, emissions trading schemes, subsidies, and feed-in tariffs as well as the reduction of solar and wind technology costs by more than 70% in the past decade. With the share of renewable energy continuing to increase, the carbon intensity of the energy sector is decreasing, so that renewable energy consumption is a key factor in stemming the rate of increasing CO2 emissions in developed countries.

4.9.3 The effect of energy intensity on carbon dioxide emissions

Based on the results of the calculation, the results were obtained that the energy intensity variable had a positive and significant effect on the increase in carbon dioxide emissions. The value of the coefficient in the energy intensity variable is 0.067223, meaning that when the energy intensity increases by 1%, it will increase carbon dioxide emissions by 0.067%, cateris paribus. These positive and significant results are in line with research conducted by (Du et al., 2024) which explains that energy intensity through economic digitalization can reduce carbon dioxide emissions. The positive and significant relationship between energy intensity and CO2 emissions can be understood because energy intensity is the amount of energy consumed per unit of GDP which then reflects how much energy input is needed to produce economic output. The higher the energy intensity, the greater the proportion of fossil energy used, so carbon emissions tend to increase proportionally. Since most of today's energy still comes from fossil fuels (such

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as oil and coal), reducing the energy used automatically reduces the amount of fuel burned. As a result, the amount of carbon dioxide (CO2) gas released into the air becomes smaller.

Other findings from Wei & Lahiri (2022) By leveraging sectoral panel data and applying econometric mediation analysis, they outlined two key findings. First, urbanization directly increases CO2 emissions in most sectors. Second, this effect is significantly mediated by the intensity of energy use, namely urbanization encourages technological inefficiency that increases the amount of energy needed per unit of output, especially in the manufacturing sector. The results show that improving energy efficiency (reducing energy intensity) in critical sectors can mitigate almost 30-40% of the increase in emissions caused by urbanization growth. These findings underscore the importance of policies that not only control the pace of urbanization, but also actively reduce energy intensity through investment in clean technologies and improved efficiency standards at the industrial level

5. Conclusion

GDP per capita has a positive and significant effect on CO2 emissions. An increase in GDP per capita by 1% leads to an increase in CO2 emissions by 0.060%. This reflects that economic growth, especially in the early and intermediate stages, tends to increase fossil energy consumption due to increased production and consumption, in line with the Environmental Kuznets Curve (EKC) pattern before reaching the turning point. Second, renewable energy consumption has a negative and significant effect on CO2 emissions. Every 1% increase in renewable energy consumption is able to reduce CO2 emissions by 0.016%. Renewable energy plays an important role in the process of decarbonizing the energy sector through fossil energy substitution mechanisms, and is supported by policies and technology costs reductions in developed countries such as the OECD. Third, energy intensity has a positive and significant influence on CO2 emissions. An increase in energy intensity by 1% increases CO2 emissions by 0.067%. This suggests that the greater the energy consumption to produce economic output, the higher the emissions produced, especially if the energy used comes from fossil sources. Therefore, energy efficiency is key in reducing emissions, especially in energy-intensive industrial sectors.

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