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Exploring the relationship between economic activity, population, and energy consumption on environmental degradation in 10 OIC Countries

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ABSTRACT

Environmental degradation is a manifestation of ecosystem damage caused by unsustainable activities, one of which is reflected in increased carbon emissions. This study aims to analyze the relationship between economic activities and environmental degradation in 10 member countries of the Organization of Islamic Cooperation (OIC) using quantitative data from 2008 to 2022. The Panel VECM method was used to identify long-term and short-term relationships between variables. The estimation results indicate that, in the long term, population, electricity consumption, economic growth, FDI, and renewable energy consumption have a significant impact on carbon emissions. Conversely, total energy consumption and the HDI are not significant. These findings encourage the government to shift from fossil fuel use to new and renewable energy and minimize the conversion of green areas into residential areas. Additionally, fossil fuel use must be balanced with investments in new and renewable energy to control rising carbon emissions alongside economic activities.

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1. Introduction

Environmental degradation is one of humanity's classic problems that seems never-ending. This issue of environmental degradation often arises as a result of human actions, such as carbon emissions. The increase in carbon emissions today seems to be a task that must be addressed by every country. One of the causes is the growth of economic activities that overexploit the environment, leading to the destruction of natural ecosystems. Numerous studies on environmental degradation have been conducted by academics and policymakers. However, exploration is essential for a country to enhance the well-being of its people toward self-reliant development and a sustainable environment (Akpan & Akpan, 2012).

One indicator of increasing environmental degradation is rising carbon emissions. Carbon emissions are the process of releasing carbon dioxide (CO2) gas. Carbon emissions are one of the main causes of global climate change and global warming. Additionally, one of the indicators used to measure the environmental quality of an area is the level of carbon emissions. Poku (2016) in his research revealed that one of the causes of increasing carbon emissions is industrialized countries that continuously use fossil fuels such as oil and coal, which contribute to global climate change. As also illustrated in Figure 1 below.

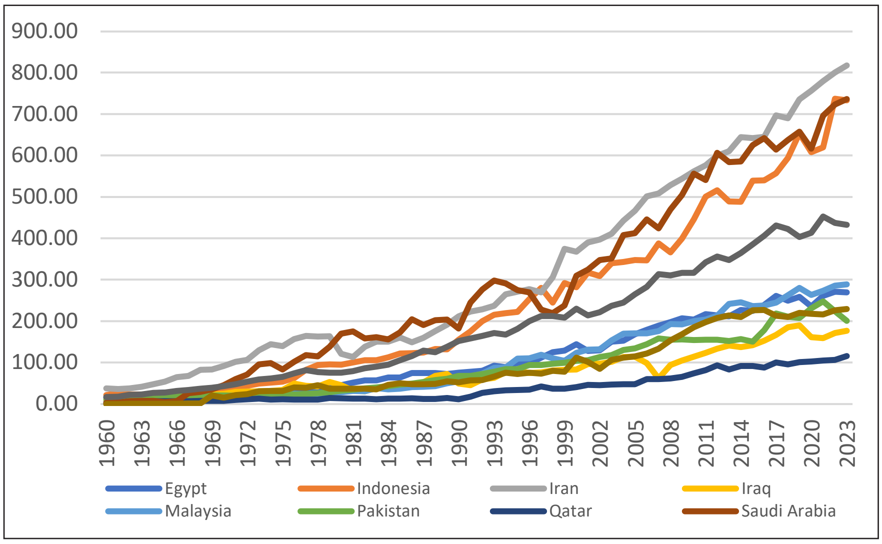

Figure 1. Carbon Emission Levels of 10 OIC Countries (MtCO2)

Sources: Global Carbon Atlas, 2024

Figure 1 illustrates the carbon emission levels in 10 OIC countries, including Indonesia, Saudi Arabia, Egypt, Pakistan, Qatar, Iran, Iraq, Turkey, Malaysia, and the United Arab Emirates. Data obtained from the Global Carbon Atlas confirms that carbon emissions have been increasing since the 1960, coinciding with the onset of industrialization in these countries. Among the 10 OIC countries, three have experienced the highest rates of carbon emissions growth between 1960 and 2023. First is Iran, where carbon emissions in 1960 were 37,36 MtCO2 and increased to 817,88 MtCO2 by 2023. Over a 63-year period, carbon emissions in Iran increased by 2.189 percent. Second on the list is Saudi Arabia. In 1960 Saudi Arabia's carbon emissions were 2,67 MtCO2, increasing to 25,49 MtCO2 by 1967. The emissions continued to rise, reaching 736,21 MtCO2 by 2023, placing Saudi Arabia second among the 10 OIC countries. Third on the list is Indonesia. As a developing country, Indonesia is also among the world's largest contributors to carbon emissions, ranking third among the 10 OIC countries. By 2023, Indonesia contributed 733,22 MtCO2 in carbon emissions.

Economic growth over the past few decades has seemed like a race for every country, even being seen as the sole measure of a nation's progress. However, economic growth is considered one of the causes of environmental degradation. As a country's economic growth increases, so does the demand for energy to support industrial activities, transportation, and domestic use. Additionally, economic growth often drives the expansion of energy-intensive industrial sectors, such as manufacturing, construction, and mining. Urbanization that follows economic growth increases the need for transportation, electricity, and housing, which in turn results in higher carbon emissions. Several studies have revealed that economic growth has a significant impact on the increase in CO2 emissions (Abdouli & Omri, 2021; Ali & Ali, 2020; Mehrjo et al., 2022).

In addition, population growth is also an issue that every country faces, especially developing countries. Population growth can have both positive and negative effects. One of the negative effects of population growth is that it can cause environmental degradation. Research conducted by Nasir & Rehman (2011) revealed that countries with large populations should bear greater responsibility for increasing CO2 emissions. This is because CO2 emission levels in developing countries are higher because they are not required to comply with the agreements outlined in the Kyoto Protocol (Nasir & Ur Rehman, 2011).

The use of fossil fuels such as oil and coal also contributes to increased CO2 emissions and global warming (Naseem et al., 2022; Sohag et al., 2017). Although some countries have actively promoted innovation and results from renewable energy, the consumption of fossil fuels continues. In developing countries, they require significant costs to purchase environmentally friendly machinery. The use of renewable energy is considered highly effective in reducing fossil fuel consumption. Therefore, in the long term, fossil fuel consumption is expected to reach 0 percent (Aslan et al., 2022; Mehmood, 2022; Muhammad & Khan, 2021; Radmehr et al., 2022; Saqib et al., 2022). The role of Foreign Direct Investment (FDI) is crucial in helping to reduce environmental degradation caused by existing technologies. Through FDI, developing countries can access knowledge and technology transfers, thereby mitigating environmental damage, particularly in terms of increased CO2 emissions (Adrian et al., 2023; Muhammad & Khan, 2021).

Based on the studies discussed, the author was motivated to conduct similar research on the relationship between economic activity, population, energy consumption, and environmental degradation. The uniqueness of this study lies in its research object and analysis method. There is still little research examining the relationship between these variables in countries with Muslim-majority populations. The purpose of this study is to examine the extent of the short-term and long-term relationships and changes in economic activity, population, and energy consumption on environmental degradation in countries with Muslim-majority populations. This study is expected to contribute to policies on carbon emission-related economic activity in 10 OIC countries.

2. Literature Review

The theoretical approach in this study uses the Environment Kuznet Curve (EKC) hypothesis. This theory was proposed by Grossman & Krueger (1991) as an adaptation of the Kuznet Curve. EKC is used to analyze the relationship between economic activity and environmental quality. The relationship between economic growth and the environment has an inverted U-shaped relationship, which is divided into three phases (scale, composition, and technology). The scale effect shows that increased production pollutes the environment. Meanwhile, the composition effect shows a shift in the economic sector. Environmental degradation appears to increase during the transition from agriculture to industry, while pollution levels decrease significantly after the transition from industry to services. The technology impact shows that environmentally friendly technology and industrial practices (Xu et al., 2022).

According to the EKC hypothesis, economic development can benefit the environment in the long term, even though it may cause significant and irreversible damage to the environment in the short term. Grossman & Kruger (1991) in their study showed that environmental damage can be reduced with economic growth. In a different study, Panayotou (1993) estimated the EKC for different environmental indicators alongside nominal GDP at the end of the 1980s. The analysis concluded that the EKC was valid for all estimated curves. The analysis also revealed that environmental damage could be mitigated with the help of high income levels because economic growth could be an effective way to improve environmental quality, especially in developing countries (Panayotou, 1993).

3. Hypotesis Development

Based on several studies that have been described and considering the theory used, namely the Environment Kuznet Curve (EKC), the hypotheses in this study are as follows:

a. Population Growth and Carbon Emissions
Population growth leads to an increase in basic needs such as food, housing, transportation, and energy. Meeting these needs drives production and consumption activities that rely on fossil-based energy, thereby contributing to increased carbon emissions.

H1: Population growth affects carbon emissions.

b. Energy Consumption and Carbon Emissions
Energy consumption, especially from fossil fuels such as oil, gas, and coal, directly produces CO_2 emissions. The higher a country's energy consumption, the greater the amount of carbon emissions released into the atmosphere.

H2: Energy consumption affects carbon emissions.

c. Electricity Consumption and Carbon Emissions
Most electricity production in many countries still relies on fossil fuel power plants. Increased electricity consumption means increased electricity production, which has the potential to increase carbon emissions.

H3: Electricity consumption affects carbon emissions.

d. Economic Growth and Carbon Emissions
Economic growth drives industrialization, infrastructure development, and increased consumption of goods and services. This increased economic activity tends to increase the use of fossil fuels, thereby contributing to an increase in carbon emissions.

H4: Economic growth affects carbon emissions.

e. Foreign Direct Investment (FDI) and Carbon Emissions
FDI brings capital, technology, and encourages industrial development. If the technology used is not environmentally friendly, an increase in FDI can increase the volume of industrial production, which generates higher carbon emissions.

H5: Foreign Direct Investment (FDI) affects carbon emissions.

f. Renewable Energy and Carbon Emissions
The use of renewable energy such as solar, wind, water, and biomass can reduce dependence on fossil fuels. Increasing the proportion of renewable energy in the national energy mix will reduce carbon emissions.

H6: The use of renewable energy affects carbon emissions.

g. Human Development Index (HDI) and Carbon Emissions
An increase in HDI reflects improvements in quality of life through education, health, and higher purchasing power. These conditions can increase energy consumption and goods that have the potential to increase carbon emissions. However, an increase in HDI can also encourage environmental awareness and the use of clean technology, which actually reduces carbon emissions.

H7: The Human Development Index (HDI) affects carbon emissions.

4. Research Method

This study uses a quantitative approach with panel data. The population of this study is all 57 OIC countries, with a sample of the 10 largest economies from the member countries of the Organization of Islamic Cooperation (OIC). These include Iran, Indonesia, Saudi Arabia, Turkey, the United Arab Emirates, Malaysia, Egypt, Pakistan, Iraq, and Qatar, taken from 2008 to 2022. The independent variables in this study are carbon emissions (CO2) in metric tons of carbon dioxide (MtCO2), population (POP) in persons per year, energy consumption (ENU) in quadrillion Btu, and electricity consumption (EPC) in billion kWh. Economic Growth (EG) is measured in percent per year, foreign direct investment (FDI) is measured in net inflow in US dollars, renewable energy consumption (REC) is measured in quadrillion Btu, and the human development index (HDI) is measured in human development index (HDI).

The analytical tool used in this study is the Panel *Vector Error Correction Model* (PVECM). PVECM is part of *Vector Autoregression* (VAR) and belongs to the category of multivariate time series analysis (Firdaus, 2020). The researchers used Panel VECM analysis to examine the long-term and short-term relationships between several economic and energy variables and increased environmental degradation in 10 Muslim countries that are members of the Organization of Islamic Cooperation (OIC). The Panel VECM model was used to perform dynamic estimation between variables without considering exogeneity issues (Firdaus, 2020). The testing process began with a stationarity test using the unit root test, optimal lag test, VAR stability test, Johansen cointegration test, Panel VECM test, and Granger causality test. The PVECM equation is as follows:

$$\begin{aligned}\Delta LogCO2_t = \alpha_{io} &+ \sum_{i=1}^{k-1} \alpha_1 \Delta LogPOP_{t-1} + \sum_{i=1}^{k-1} \alpha_2 \Delta LogENU_{t-1} + \sum_{i=1}^{k-1} \alpha_3 \Delta LogEPC_{t-1} + \sum_{i=1}^{k-1} \alpha_4 \Delta EG_{t-1} \\ &+ \sum_{i=1}^{k-1} \alpha_5 \Delta LogFDI_{t-1} + \sum_{i=1}^{k-1} \alpha_6 \Delta LogREC_{t-1} + \sum_{i=1}^{k-1} \alpha_7 \Delta LogHDI_{t-1} + \gamma ECT_{t-1} + \beta_0 \\ &+ \beta_1 LogCO2_{t-1} + \beta_2 LogPOP_{t-1} + \beta_3 LogENU_{t-1} + \beta_4 \Delta LogEPC_{t-1} + \beta_5 EG_{t-1} + \beta_6 LogFDI_{t-1} \\ &+ \beta_7 LogREC_{t-1} + \beta_8 LogHDI_{t-1} + \varepsilon_t\end{aligned}$$

Description:
LogCO2 = Carbon Emission (CO2)
LogPOP = Population

LogENU = Energy Use/Energy Consumption
LogEPC = Electricity Consumption
EG = Economic Growth
LogFDI = Foreign Direct Investment
LogREC = Renewable Energy Consumption
LogHDI = Human Development Index (HDI)
ECT_{t-1} = *Error Correction Term*
α_0 = Koefisien jangka pendek
$\alpha_1, \alpha_2,..\alpha_n$ = Koefisien Hubungan Jangka Pendek
β_0 = short-term coefficients
$\beta_1, \beta_2 ... \beta_n$ = long-term relationship coefficients
ε_t = *Error term*
k = *lag length* (ordo)
γ = *Speed of adjustment*

5. Result

Statictics Description

The descriptive statistics in Table 1 summarize the distribution of the variables used in this study, based on 150 observations. Carbon emissions (CO2) show a mean of 5.59 MtCO2 with relatively low variability (standard deviation = 0.64), suggesting that emissions remain fairly stable across the study period. Population (POP) records a mean of 17.59, indicating steady demographic growth with a narrow dispersion (standard deviation = 1.37). Energy consumption (ENU) has a mean of 1.43 quadrillion Btu but displays noticeable variation, ranging from 0.07 to 2.60 quadrillion Btu, which points to substantial differences in energy use across observations. Electricity consumption (EPC) is more evenly distributed, with a mean of 4.85 billion kWh and a standard deviation of 0.71, indicating consistent patterns of electricity use.

Economic growth (EG) shows the widest fluctuations, with a mean of 4.02% but ranging from -12.03% (economic contraction) to 19.59% (strong expansion), reflecting significant volatility over time. Foreign direct investment (FDI) appears relatively stable, with a mean value of 22.30 and low variability (standard deviation = 1.10). Renewable energy consumption (REC) records a negative mean (-3.37), suggesting an overall decline in renewable energy utilization during the observation period, coupled with substantial variability (standard deviation = 2.47). Finally, the human development index (HDI) also exhibits a slightly negative mean (-0.30) with moderate dispersion (standard deviation = 0.15), implying that HDI growth was generally below the baseline reference point used in the data. Overall, these descriptive statistics indicate that while population, carbon emissions, electricity consumption, and FDI are relatively stable, variables such as economic growth and renewable energy consumption exhibit considerable volatility that may have a strong impact on the relationship being examined.

Table 1. Descriptive Statistics

Variable	Mean	Median	Maximum	Minimum	Stand. Dev.	Observasi
CO2	5.593154	5.473680	6.685545	4.121261	0.644842	150
POP	17.58782	17.84492	19.43410	14.18312	1.374574	150
ENU	1.435121	1.383238	2.602842	0.072583	0.623009	150

Variable	Mean	Median	Maximum	Minimum	Stand. Dev.	Observasi
EPC	4.850552	4.982295	5.974352	3.000023	0.712824	150
EG	4.023451	4.479420	19.59233	-12.03679	4.144086	150
FDI	22.30361	22.35104	24.05744	18.14754	1.108589	150
REC	-3.369656	-2.964407	0.000000	-12.58817	2.468246	150
HDI	-0.300657	-0.251030	-0.065072	-0.715393	0.154458	150

Data Stationarity Test

Based on the results of the stationarity test in Table 2, it is known that some of the variables tested at the level show non-stationary results, as indicated by probability values of less than 0.05. Of the eight variables tested for stationarity at the level, four variables show stationary results. All variables showed stationary results in the first difference level test, as evidenced by probability values less than 0.05. Based on the stationarity test that has been conducted, all variables have met the unit root test data requirements and all data variables are stationary at the first difference level.

Table 2. Stationarity Test

No	Variable	Level			Difference		
		Stat.	Prob.	Ket	Stat.	Prob.	Ket
1	Log_CO2	24.5363	0.2197	Not Stationary	87.1658	0.0000	Stationary
2	Log_POP	29.7905	0.0733	Not Stationary	55.2937	0.0000	Stationary
3	Log_ENU	44.7425	0.0012	Stationary	77.7207	0.0000	Stationary
4	Log_EPC	24.6306	0.2159	Not Stationary	77.7197	0.0000	Stationary
5	EG	52.2522	0.0001	Stationary	85.9871	0.0000	Stationary
6	Log_FDI	50.6781	0.0002	Stationary	94.4112	0.0000	Stationary
7	Log_REC	42.8147	0.0022	Stationary	68.3518	0.0000	Stationary
8	Log_HDI	15.7897	0.7296	Not Stationary	42.1005	0.0027	Stationary

Optimal Lag Test

The optimal lag test in Table 3 shows that the optimal lag length is lag 5, as indicated by the highest *sequential modified* LR *test statistic* and *Akaike Information Criterion* (AIC) values, which are 96.31280 and -12.60751, respectively. Based on these results, the lag used in this study is lag 5, and the study can proceed with testing the stability of the VAR.

Table 3. Lag Length Criteria Test

Lag	LogL	LR	FPE	AIC	SC	HQ
0	464.0581	NA	5.48e-15	-10.13462	-9.912419*	-10.04502
1	604.7508	253.2469	1.00e-15	-11.83891	-9.839060	-11.03245*
2	700.7964	155.8072	5.07e-16*	-12.55103	-8.773541	-11.02772
3	755.5479	79.08547	6.77e-16	-12.34551	-6.790376	-10.10535
4	806.8874	65.03002	1.06e-15	-12.06416	-4.731389	-9.107158
5	895.3379	96.31280*	8.24e-16	-12.60751*	-3.497091	-8.933653

VAR Stability Test

The VAR stability test can be considered stable if all roots in the polynomial function are within the unit circle, so that the *Impulse Response Function* (IRF) and *Forecast Error Variance Decomposition* (FEVD) can be considered valid (Firdaus, 2020). Figure 2 shows that the model used in this study is stable, as evidenced by all the roots of the polynomial function being within the unit circle, so that the results of the IRF (*Impulse Response Function*) and VD (*Variance Decomposition*) analysis are valid.

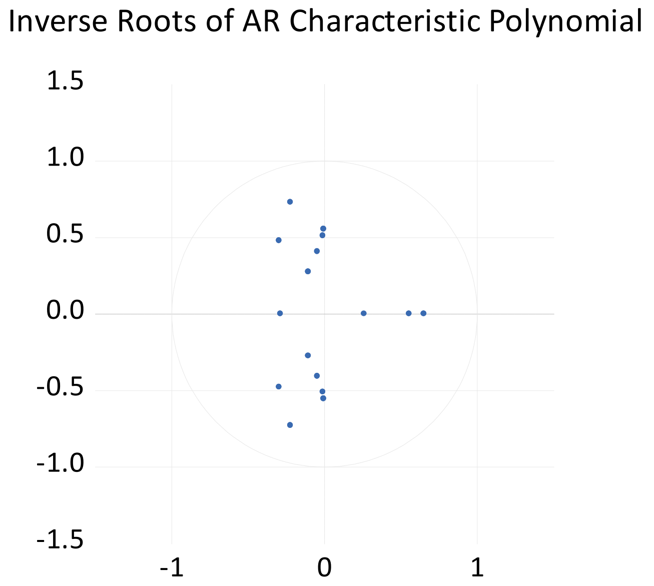

Figure 2. VAR Stability Test

Johansen Cointegration Test

The next stage of testing in the Panel VECM testing system is the cointegration test. The cointegration test is conducted to detect whether there is a long-term relationship between each variable. If there is a long-term relationship, the research can continue, but if there is no cointegration, the VAR analysis method at the first difference level is used. Table 4 shows the results of the cointegration test, indicating three cointegration relationships with critical values below 5 percent. These results indicate the existence of long-term relationships.

Additionally, the results of the Panel VECM also show an F-statistic value of 3.4351, which is greater than the F-Table value of 2.0172, indicating that all variables simultaneously have a significant effect. The R-Squared value obtained from the test results is 0.7875, meaning that 78,8 percent of the changes in carbon emissions (CO2) can be explained by the variables Population (POP), Energy Consumption (ENU), Electricity Consumption (EPC), Economic Growth (EG), Foreign Direct Investment (FDI), Renewable Energy Consumption (REC), and Human Development Index (HDI). Meanwhile, 21,2 percent of the carbon emissions (CO2) variable is influenced by variables outside the scope of this study.

Table 4. Johansen Cointegration Test

Unrestricted Cointegration Rank Test (Trace)				
Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.**
None *	0.693994	288.4292	159.5297	0.0000
At most 1 *	0.545726	193.6970	125.6154	0.0000
At most 2 *	0.422089	130.5727	95.75366	0.0000
At most 3 *	0.387351	86.70584	69.81889	0.0013
At most 4	0.218747	47.50876	47.85613	0.0539
At most 5	0.181258	27.76024	29.79707	0.0844
At most 6	0.108100	11.76129	15.49471	0.1687
At most 7	0.032089	2.609223	3.841465	0.1062
Unrestricted Cointegration Rank Test (Maximum Eigenvalue)				
Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	0.05 Critical Value	Prob.**
None *	0.693994	288.4292	159.5297	0.0000
At most 1 *	0.545726	193.6970	125.6154	0.0000
At most 2 *	0.422089	130.5727	95.75366	0.0000
At most 3 *	0.387351	86.70584	69.81889	0.0013
At most 4	0.218747	47.50876	47.85613	0.0539
At most 5	0.181258	27.76024	29.79707	0.0844
At most 6	0.108100	11.76129	15.49471	0.1687
At most 7	0.032089	2.609223	3.841465	0.1062

Panel Vector Error Correction Model (PVECM) Estimation

The Panel VECM estimation described in Table 5 reveals that the long-term coefficients of variables in the model that have long-term significance for carbon emissions are Population, Electricity Consumption, Economic Growth, Foreign Direct Investment (FDI), and New and Renewable Energy Consumption. while the variables that are not significant in the long term are Energy Consumption and Human Development Index (HDI).

Additionally, the results of the Panel VECM also show an F-statistic value of 3.4351, which is greater than the F-Table value of 2.0172, indicating that all variables simultaneously have a significant effect. The R-Squared value obtained from the test results is 0.7875, meaning that 78.8 percent of the changes in carbon emissions (CO2) can be explained by the variables Population (POP), Energy Consumption (ENU), Electricity Consumption (EPC), Economic Growth (EG), Foreign Direct Investment (FDI), Renewable Energy Consumption (REC), and Human Development Index (HDI). Meanwhile, 21.2 percent of the carbon emissions (CO2) variable is influenced by variables outside the scope of this study.

Table 5. Estimasi Panel VECM

Jangka Panjang		
Variable	Koefisien	T-Statistik
LOG_CO2(-1)	1.000000	
LOG_POP(-1)	0.834707	1.82507***
LOG_ENU(-1)	0.002164	0.00735
LOG_EPC(-1)	-0.700255	-2.52252**
EG(-1)	-0.011794	-1.87702*
LOG_FDI(-1)	0.107621	3.63295***
LOG_REC(-1)	0.050302	5.61135***
LOG_HDI(-1)	-1.252631	-1.43312
C	-0.012881	
Jangka Pendek		
Variable	Koefisien	T-Statistik
CointEq1	-0.568990	-1.94775*
D(LOG_CO2(-1)	-0.498349	-1.74074*
D(LOG_CO2(-2)	-0.855596	-3.16198***
D(LOG_CO2(-3)	-0.855596	-1.19413
D(LOG_CO2(-4)	-0.150388	-0.65488
D(LOG_CO2(-5)	0.224333	1.00744
D(LOG_POP(-1)	-2.523792	-1.26710
D(LOG_POP(-2)	-0.084572	-0.03889
D(LOG_POP(-3)	2.402745	0.76896
D(LOG_POP(-4)	-0.881658	-0.30926
D(LOG_POP(-5)	1.750500	1.11443
D(LOG_ENU(-1)	0.357785	1.84910*
D(LOG_ENU(-2)	0.621654	2.54617***
D(LOG_ENU(-3)	0.235821	0.90308
D(LOG_ENU(-4)	0.139890	0.52253
D(LOG_ENU(-5)	0.096987	0.46463
D(LOG_EPC(-1)	-0.597992	-2.59784***
D(LOG_EPC(-2)	-0.698933	-2.60485***
D(LOG_EPC(-3)	-0.705894	-2.70941***
D(LOG_EPC(-4)	-0.152173	-0.75692
D(LOG_EPC(-5)	-0.159451	-1.01678
D(EG(-1)	-0.005803	-1.50946
D(EG(-2)	-0.004824	-1.07991
D(EG(-3)	-0.003207	-0.65224
D(EG(-4)	-0.002719	-0.71953
D(EG(-5)	-0.001913	-0.81766
D(LOG_FDI(-1)	0.060289	1.77442*

D(LOG_FDI(-2)	0.034434	1.08558
D(LOG_FDI(-3)	0.043674	1.65119*
D(LOG_FDI(-4)	0.029267	1.62653
D(LOG_FDI(-5)	0.018273	1.74784*
D(LOG_REC(-1)	0.030659	2.15917***
D(LOG_REC(-2)	0.030776	2.27166***
D(LOG_REC(-3)	0.021670	2.21649***
D(LOG_REC(-4)	0.011797	1.64723
D(LOG_REC(-5)	0.007813	1.64309
D(LOG_HDI(-1)	-0.739955	-0.53924
D(LOG_HDI(-2)	0.449727	0.31444
D(LOG_HDI(-3)	0.202796	0.12435
D(LOG_HDI(-4)	2.520555	1.42563
D(LOG_HDI(-5)	2.594311	1.75794*
C	-0.002888	-0.27834
R-squared	0.787522	
Adj. R-squared	0.558269	
F-statistic	3.435169	

Impulse Respons Function (IRF)

The Impulse Response Function (IRF) test is derived from the results of the Panel VECM estimation and is used to illustrate the impact of shocks caused by one variable on another variable. In this study, the IRF test is used to show the response of Carbon Emissions (CO2) to shocks caused by Carbon Emissions (CO2), Population (POP), Energy Consumption (ENU), Electricity Consumption (EPC), Economic Growth (EG), Foreign Direct Investment (FDI), Renewable Energy Consumption (REC), and Human Development Index (HDI). The IRF results are shown in Figure 3.

Figure 3 illustrates the response shown by Carbon Emissions to shocks caused by Carbon Emissions (CO2), population (POP), energy consumption (ENU), electricity consumption (EPC), economic growth (EG), foreign direct investment (FDI), renewable energy (REC), and human development index (HDI). Overall, the response shown by Carbon Emissions after being given a shock of one standard deviation from the various variables tested in each period produces dynamic values. This can be seen in Figure 3, where each period shows different responses; sometimes the response shown by Carbon Emissions is positive, but sometimes the response shown by Carbon Emissions is negative. Up to period 15, the positive response of carbon emissions was caused by shocks from carbon emissions themselves of 0.034, population of 0.091, electricity consumption of 0.026, economic growth of 0.012, and human development index of 0.014. Meanwhile, the negative response shown by carbon emissions in period 15 is caused by the shocks from energy consumption of -0.001, foreign direct investment (FDI) of -0.020, and renewable energy of -0.028.

Figure 3. Impulse Response Function (IRF)

Forecast Error Variance Decomposition (FEVD)

The Forecast Error Variance Decomposition test in Panel VECM estimation is a test that aims to measure the contribution of exogenous variables to endogenous variables. The information provided in FEVD is the proportion of the movement of shocks originating from the variable itself and other variables at present and in the future. In this study, Variance Decomposition measures the contribution generated by the Population (POP), Energy Consumption (ENU), Electricity Consumption (EPC), Economic Growth (EG), Foreign Direct Investment (FDI), Renewable Energy Consumption (REC), and Human Development Index (HDI) to the Carbon Emissions (CO2) variable in terms of the proportion of the movement of shocks originating from the variable itself and other variables at present and in the future. The following are the results of the variance decomposition described in Table 6.

Table 6. Forecast Error Variance Decomposition (FEVD)

Period	1	4	8	12	15
LOG_CO2	100.0000	70.90581	43.61215	32.212	22.49187
LOG_POP	0.000000	6.121643	23.41889	31.81446	40.76724
LOG_ENU	0.000000	15.77738	12.402	9.555681	5.734194
LOG_EPC	0.000000	1.847483	4.745407	4.841517	6.639596
EG	0.000000	3.209726	5.275796	11.31562	13.95382
LOG_FDI	0.000000	1.375735	2.915941	1.800943	2.724172
LOG_REC	0.000000	0.391353	5.289379	6.396162	6.037787
LOG_HDI	0.000000	0.370862	2.340443	2.063612	1.651329

Based on Table 6, the results of the variance decomposition in the initial period show that the contribution of carbon emissions (CO2) variability comes from the carbon emissions variable itself, which is 100 percent. Meanwhile, other variables did not contribute to carbon emissions variability in the first period. In the second period, Carbon Emissions contributed 86.8 percent to their own variability, followed by Energy Consumption contributing 6.9 percent to Carbon Emissions, Population contributing 3.6 percent, and Electricity Consumption contributing 2.3 percent.

In the fourth period, Carbon Emissions contributed 70.9 percent to their own variability, which was lower than the previous period, followed by Energy Consumption, which contributed 15.8 percent to the variability of Carbon Emissions. Population contributed 6.1 percent to the variability of Carbon Emissions. Economic Growth contributed 3.2 percent to the variability of Carbon Emissions. Electricity consumption contributed 1.8 percent, and FDI contributed 1.4 percent to carbon emission diversity. Then, the variable of New and Renewable Energy Consumption contributed 0.39 percent to carbon emission diversity, and finally, the Human Development Index (HDI) contributed 0.37 percent to carbon emission diversity.

In the eighth period, carbon emissions contributed 43.6 percent to their own variability, followed by population contributing 23.4 percent to carbon emissions variability. Energy consumption contributed to carbon emissions diversity by 12.4 percent. New and renewable energy consumption contributed to carbon emissions diversity by 5.8 percent. Economic growth contributed to carbon emissions diversity by 5.2 percent, and electricity consumption contributed to carbon emissions diversity by 4.7 percent. FDI contributes to carbon emissions diversity by 2.9 percent, and the Human Development Index also contributes to carbon emissions diversity by 2.3 percent.

In the twelfth period, carbon emissions contribute to their own diversity by 32.2 percent, followed by population, which also contributes to carbon emissions diversity by 31.8 percent. Economic growth contributed to carbon emissions diversity by 11.3 percent. Energy consumption contributed to carbon emissions diversity by 9.5 percent. New and renewable energy consumption contributed to carbon emissions diversity by 6.4 percent. Electricity consumption contributed to carbon emissions diversity by 4.8 percent. HDI contributed to carbon emission diversity by 2.1 percent, and FDI also contributed to carbon emission diversity by 1.8 percent.

In the last period, namely the fifteenth period, the variable that contributed most to carbon emission diversity did not originate from the carbon emission variable itself, as in previous periods. Instead, the Population variable contributed the most to Carbon Emissions diversity, at 40.8 percent. Meanwhile, Carbon Emissions contributed to their own diversity by 22.5 percent, followed by Economic Growth, which contributed to Carbon Emissions diversity by 13.9 percent. Electricity consumption contributed to Carbon Emissions diversity by 6.6 percent. Renewable energy consumption contributes 6.0 percent to carbon emissions diversity. Energy consumption contributes 5.7 percent to carbon emissions diversity. FDI contributes 2.7 percent to carbon emissions diversity, and HDI contributes 1.6 percent to carbon emissions diversity.

6. Discussion

Relationship between Population and Carbon Emissions

The results of the VECM estimation conducted between carbon emissions and population, as shown in Table 4, indicate a long-term relationship, while in the short term there is no significant relationship. This can be explained by the fact that population growth in the short term does not affect carbon emissions, but in the long term it has a significant impact on carbon emissions. As also explained in the IRF test, the response shown by carbon emissions due to shocks caused by population indicates that in the early to mid-period, the response is small, both positive and negative, but in the long term, there is a high shock. This confirms the results of the VECM estimation that in the long term, population has a significant contribution to the increase in carbon emissions.

Based on these results, from a theoretical perspective, this confirms the EKC theory, where economic activity can lead to environmental degradation, one of which is population growth (Grossman & Krueger, 1991). This occurs because population growth implies increased demand for energy sources, reduced land availability due to the establishment of new settlements, and increased consumption of resources and production of goods and services, which in turn contribute to increased carbon emissions. The results of this study are in line with a study conducted by Khan (2021) in the United States, which also revealed that long-term population growth is correlated with increased carbon emissions.

Relationship between Energy Consumption and Carbon Emissions

The results of the VECM estimation conducted between carbon emissions and energy consumption, as shown in Table 4, indicate that there is no long-term relationship. However, there is a short-term relationship between Energy Consumption and Carbon Emissions. This can be explained by the fact that short-term energy consumption can lead to increased carbon emissions, as many developing countries still rely heavily on fossil fuels for their economic activities. This contrasts with developed countries, which are more concerned with environmental sustainability.

The VECM analysis is also supported by the IRF test, where the response shown by carbon emissions due to shocks caused by energy consumption exhibits fluctuating responses throughout the initial to final periods, both positive and negative, thereby confirming the VECM estimation results that, in the long term, population does not significantly contribute to increased carbon emissions. This is because energy conditions and prices are also fluctuating at any given time, thus affecting the short term but not yet the long term. On the other hand, the limited availability of resources will prompt these countries to shift to renewable energy sources that can reduce carbon emissions. However, this can only occur if the country has good economic growth, thereby fostering awareness of the need to improve environmental quality.

Based on these results, a theoretical analysis confirms the EKC theory, where economic activity can lead to environmental degradation, one of which is increased energy consumption (Grossman & Krueger, 1991). This occurs because countries with developing economies or rapidly growing industries tend to have higher energy consumption due to increased energy needs for industrial activities, transportation, and infrastructure. Energy consumption can come from fossil fuel sources (such as coal, oil, and natural gas) or renewable energy sources (such as wind, solar, hydro, and bioenergy). Many OIC countries, which are predominantly developing nations, rely heavily on fossil fuels as one of their export commodities and for their economic activities, resulting in higher carbon emissions. These results are also in line with studies conducted by Majeed (2020), Rehman (2017) and Adrian (2023), which also revealed that energy consumption is correlated with increasing carbon emissions.

Relationship Between Electricity Consumption and Carbon Emissions

The relationship between electricity consumption and carbon emissions based on VECM analysis shows that in the long term, electricity consumption negatively affects carbon emissions, meaning that an increase in electricity consumption will reduce carbon emissions. Similarly, in the long term, the relationship between electricity consumption and carbon emissions also has a negative effect in the short term. The results obtained from the VECM analysis are also supported by the results of the IRF test, where the dominance of the response caused by the shock induced by electricity consumption tends to be negative. This condition can be interpreted to mean that in the 10 OKI countries, electricity consumption is not entirely sourced from fossil fuels but rather from renewable energy, thereby not increasing carbon emissions but rather reducing them.

Based on these results, from a theoretical perspective, this confirms the EKC theory, where economic activity in the long term can reduce environmental degradation, one of which is the increase in electricity consumption (Grossman & Krueger, 1991). This occurs because these OIC countries do not solely rely on electricity sources from fossil fuels but also from other sources, such as Indonesia, which utilizes massive hydroelectric power plants (PLTA) in several regions across the country. These results generally contradict studies conducted by Radmehr (2021) and Satrovic (2022), which revealed that electricity consumption has an impact on increasing carbon emissions.

Relationship between Economic Growth and Carbon Emissions

The VECM estimation results as described in Table 4 show that in the long term, economic growth affects the increase in carbon emissions. Meanwhile, in the short term, economic growth has no effect on the increase in carbon emissions. As also explained in the IRF test, the response shown by carbon emissions due to shocks caused by economic growth indicates that in the early to mid-period, the response is small, both positive and negative, but in the long term, there is a high shock. This confirms the results of the VECM estimation that in the long term, economic growth has a significant contribution to the increase in carbon emissions.

Based on these results, from a theoretical perspective, this confirms the EKC theory, where long-term economic growth can reduce environmental degradation (Grossman & Krueger, 1991). These results generally align with studies conducted by Tariq (2022) and Yusuf (2023), which revealed that their research aligns with the EKC theory, confirming the U-shaped curve in the EKC model and proving that economic growth has an impact on reducing carbon emissions in the long term.

Relationship Between Foreign Direct Investment (FDI) and Carbon Emissions

The relationship between FDI and increased carbon emissions in 10 OKI countries based on VECM estimation results shows that FDI in the long term contributes to increased carbon emissions in 10 OKI countries, while in the short term, FDI also has an impact on increased carbon emissions. The VECM results can also be explained as in the IRF test. Where the response shown by carbon emissions due to shocks caused by FDI indicates that in the early to mid-period, it only provides a small response, both positive and negative, but in the long term, there is a high shock. This then confirms the results of the VECM estimation that in the long term, FDI has a significant role in increasing carbon emissions.

Based on these results, from a theoretical perspective, this confirms the EKC theory, where economic activity in the long term can increase carbon emissions. This can occur because

FDI in the 10 OKI countries is largely directed toward carbon-intensive sectors, such as mining and coal-based energy industries, among others, which can lead to potential carbon emissions. Moreover, these 10 countries are developing countries with lax environmental standards, which attract investors seeking lower production costs. These results are generally in line with studies conducted by Ganda (2022) and Kahouli (2022), which reveal that foreign direct investment has an impact on increasing carbon emission levels.

Relationship between Renewable Energy Consumption and Carbon Emissions

The VECM estimation results in Table 4 show that in the long term, new and renewable energy consumption affects the increase in carbon emissions. Meanwhile, in the short term, the increase in carbon emissions is also influenced by new and renewable energy consumption. The results of the VECM estimation can also be explained in the IRF test, where the response shown by carbon emissions due to shocks caused by renewable energy consumption indicates that in the initial to mid-term period, the response is small, both positive and negative, but in the long term, there is a high shock with a tendency toward negative responses. This confirms the results of the VECM estimation that, in the long term, the consumption of new and renewable energy has a significant impact on changes in carbon emission levels.

Based on these results, referring to the EKC theory, this proves that the results do not confirm the concept in the theory where an increase in the consumption of new and renewable energy should reduce carbon emission levels. However, this study suggests the opposite. This may occur because the use of new and renewable energy is perceived as not yet yielding maximum results in reducing fossil fuel consumption. On the other hand, countries with low renewable energy consumption, such as Saudi Arabia and Qatar, remain heavily reliant on fossil fuels as their primary energy source. This reliance contributes to high carbon emissions, despite both countries having significant capacity to invest in renewable energy. Thus, the use of new and renewable energy in the 10 OIC countries has not had an impact on reducing carbon emissions. These results generally contradict studies conducted by Khan (2021) and Xu (2022), which revealed that the consumption of new and renewable energy has an influence on reducing carbon emissions.

Relationship Between the Human Development Index (HDI) and Carbon Emissions

The VECM estimation results, as shown in Table 4, indicate that in the long term, the Human Development Index (HDI) does not influence an increase in carbon emissions. However, in the short term, an increase in carbon emissions is influenced by the consumption of new and renewable energy at a lag of 5. This indicates that increases or decreases in the Human Development Index do not affect carbon emission levels.

Based on these results, referring to the EKC theory, an increase in economic income indirectly also increases the Human Development Index in a country, thereby increasing public awareness of environmental sustainability. These results prove that this analysis has not confirmed the concept in the EKC theory, which states that an increase in HDI should reduce carbon emissions.

7. Conlusions

Based on the results of research on the relationship between economic activity, population, and energy consumption on environmental degradation as measured by carbon emission levels using Panel Vector Error Correction Model (VECM) analysis, several important findings were obtained. First, the VECM estimation results reveal that in the long term, the variables of population, electricity consumption, economic growth, FDI, and consumption of new and renewable energy have a significant effect on carbon emission levels. Conversely, the variables of energy consumption and the Human Development Index (HDI) do not show significant effects in the long term. In the short term, increases in carbon emissions are influenced by the carbon emissions variable itself (at lags 1 and 2), energy consumption (lags 1 and 2), electricity consumption, FDI, and renewable energy consumption. Meanwhile, population, economic growth, and HDI do not have a significant impact in the short term.

The findings of this study have important implications for governments and stakeholders in the 10 member countries of the Organization of Islamic Cooperation (OIC) that were the subject of the study. High population growth has the potential to increase carbon emissions as energy needs rise, necessitating efforts to transition from fossil fuels to renewable energy sources. Additionally, it is important to minimize the conversion of green spaces into residential areas to curb the rate of carbon emissions increase. On the other hand, the use of fossil fuels needs to be balanced with increased investment in new and renewable energy to prevent a surge in emissions due to economic activities. However, this study has limitations as it only covers 10 OIC member countries (Iran, Indonesia, Saudi Arabia, Turkey, the United Arab Emirates, Malaysia, Egypt, Pakistan, Iraq, and Qatar) with a relatively short panel data period. Therefore, the results of this study cannot yet be generalized broadly. For future research, it is recommended that the number of countries be expanded and the observation period extended, so that the results obtained can provide a more comprehensive and representative picture.

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