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Research Article

THE NEXUS BETWEEN TRADE OPENNESS AND ENVIRONMENTAL DEGRADATION: A VECM ANALYSIS

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Abstract
This research aimed to analyze the influence of trade openness, ICT, per capita income, and Human Development Index on environmental quality in Upper-Middle Income countries in the short and long term and how per capita income influenced environmental quality in the U-shaped EKC hypothesis in Upper-Middle Income countries over the 1990-2020 periods using the VECM Panel analysis. Several findings were revealed in this research. First, the coefficient of trade openness in the long-term and short-term on environmental quality was positive and statistically significant at the 1% level. Second, the relationship between ICT and environmental quality had a positive influence in the short term and a negative influence in the long term. Third, the relationship between per capita income and environmental quality had a positive influence in the long and short-term. In these findings, an increase in per capita income increased carbon dioxide which caused a decrease in environmental quality and emerged an inverted U relationship in the long- and short-term of the EKC hypothesis in UMI countries with the turning point in the short-term being US$ 728,530 and in the long-term US$ 772,839. Finally, the Human Development Index in this research has a positive influence in the short- and long-term on environmental quality. The outcomes of this study have considerable Policy implication regarding trade openness policy formulation to reduce environmental degradation especilly in Upper Middle Income Countries.

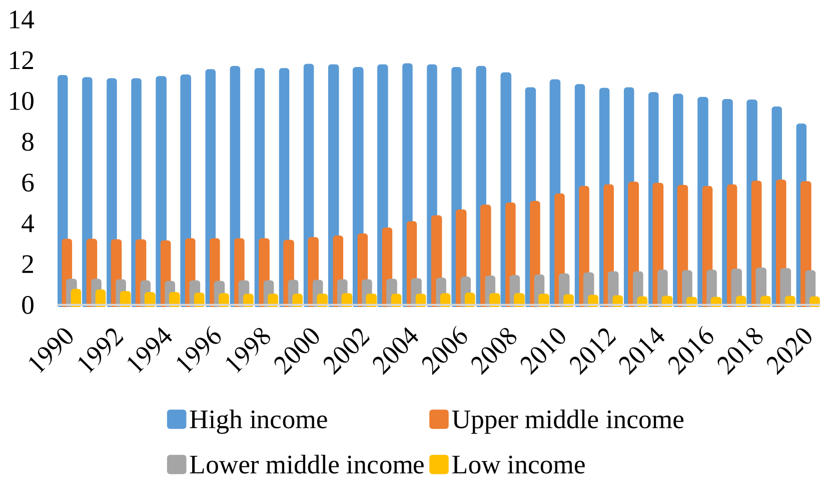
Keywords: EKC, Environment, ICT, Income, Trade Openness

INTRODUCTION

Currently, village governance receives significant attention in the Republic of Indonesia. This is because the government allocates the Village Fund Allocation from the regional budgets of districts or provinces, as well as village funds sourced from the Ministry of Villages (Syapsan, 2020). With an annual allocation exceeding 1 billion, they face significant challenges related to fund management to prevent misuse by village officials or heads (Amaliah, 2022). One pressing issue is the enhancement of village officials' competencies to improve their currently perceived low performance (Widyawati & Anggraini, 2023). The poor performance of village government officials is evident in widespread public complaints about service quality, such as delays and unauthorized fees in handling civil registration, land permits, and birth certificates, with over 70% of complaints stemming from these issues (Phoek et al., 2024). Juwita and Murti (2023) emphasize that competencies are crucial as they reflect individuals' capabilities in performing their duties, encompassing knowledge, skills, abilities, and personal attributes influencing performance and behavior (Apriana et al., 2020). Pongantung et al. (2022) further assert that higher competency levels correlate with better performance, underscoring the need for continuous competency improvement to ensure effective task execution (Yulianto, 2020).

Environmental degradation is a serious problem facing the world community today. Environmental degradation will reduce sustainability and cause many challenges facing humanity, such as climate change, water scarcity, inequality and hunger. Environmental degradation can also reduce the level of economic development. It can reduce the productivity of natural resources and cause a variety of problems, ranging from health issues to reduced living comfort (Jorgenson et al., 2010; G. Ma et al., 2017). Climate change and global warming are among the consequences of environmental degradation and are the biggest challenges facing the world today. A significant cause of global warming is greenhouse gas emissions (Shahbaz et al. 2019). Over the years carbon dioxide (CO2) emissions have received great attention as a measure of environmental degradation in the literature (Tiba and Omri, 2017).

Enhancement of CO2 is a major threat to global warming, and the ongoing climate change has become an important concern for all societies. Figure 1 shows the significant decline in CO2 in high-income countries which, however, still remains higher than in other groups of countries. Apart from high-income countries, low-income countries also experienced a significant decline. Overall, there was a sharp increasing trend in CO2 emissions per capita in Upper Middle Income (UMI) countries from 1990 to 2020.



Source: World Bank, 2023

Figure 1. Global Country Carbon Dioxide Emissions 1990-2020 (metric tons per capita)

UMI countries are countries with rapid economic growth that use large amounts of energy in the form of fossil fuels which emit large amounts of carbon, causing an increase in carbon dioxide emissions. Currently, UMI countries are in the process of opening-up rapid trade which has created major challenges for the environment, especially in terms of CO emissions (Mujtaba, 2020; Murshed, 2020)). Theoretically, trade openness plays an important role in determining CO2 emissions (Antweiler et al., 2001).

Based on Table 1, in the last three decades, these countries have achieved higher economic growth by transforming their economies from primary agricultural sectors to energy and ICT-based industrial sectors. This can be seen from the growth in the contribution of the industrial sector from the first decade, namely 1990 to 2019, which got an increase in the second decade in 2000 to 2009 by 36.31%. However, it experienced a decline in the third decade in 2010 to 2019 by 35.74%. Unfortunately, the agricultural sector in the last three decades has always experienced a decline. To encourage sustainable economic growth, currently, UMI countries are consuming around 29.42% of the world's energy and emitting 30.02% of the world's total CO_2 emissions with the percentage of increase of 8.23% over the period of 1990–2010.

Table 1. Average Contribution of Industry, Agriculture, Energy, CO2 Emissions, and Population of Upper Middle Income Countries (%)

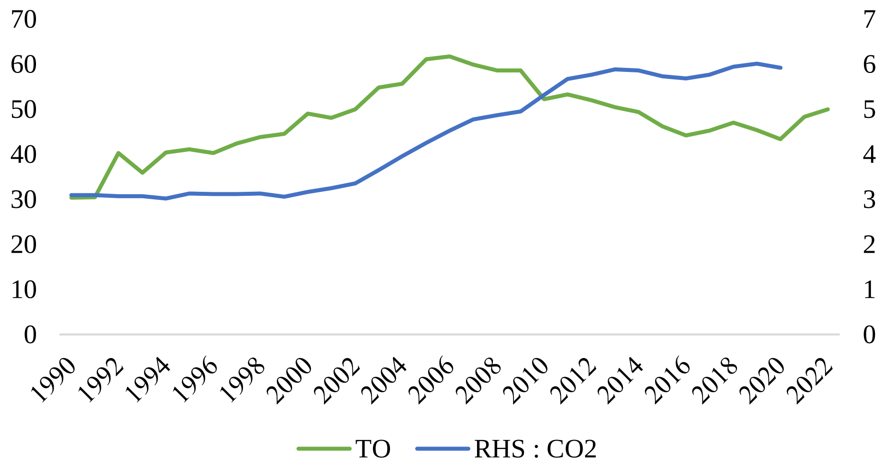
Variable	Decade I (1990-1999)	Decade II (2000-2009)	Third Decade (2010-2019)
Industry	35.53	36.31	35.74
Agriculture	10.84	8.01	6.99
Energy	21.58	23.9	29.42
CO2 emissions	21.79	26.2	30.02
Population	36.31	35.83	34.81
ICT	3.75	3.61	6.64

Note: Industry and agriculture contribute to GDP
Energy and ICT is use
Source: World Bank, 2023

Currently, the share of UMI countries in energy use and CO emissions2 clearly shows that in-depth study of the dynamic linkage of energy consumption and CO2 emissions is a serious academic and policy requirement which has previously been neglected. Moreover, this kind of investigation becomes even more interesting because almost 35% of the world's population lives in UMI countries. The main obstacles for UMI countries in their dilemma between trade openness and the environment are limited natural resources, inadequate levels of expert expertise, and poor infrastructure to dampen the adoption of renewable energy in these countries (Martinot et al., 2002; Negro, Alkemade & Hekkert 2012). Another fundamental problem faced by those countries is achieving better environmental quality and sustainable development in the current decade. Increasing direct and indirect human activities in UMI are causing severe damage to human health, ecological disasters, and environmental deficits. Therefore, increased carbon dioxide has become a common problem in UMI countries, so it is important to know the factors behind this problem.

Based on the Heckscher-Ohlin theory, a country's production function will tend to export commodities that are relatively intensive in using relatively abundant production factors due to their abundance and low price (endowment factors). In accordance with the Factor Endowment Hypothesis (FEH), countries that have a comparative advantage in producing goods that cause a lot of pollution will increase their production to meet growing global market demand, resulting in an increase in carbon emissions. This argument implies that trade openness may result in higher levels of pollution (Temurshoev, 2006; Kusuma, 2020; Suwarni, 2021; Hoa et al., 2023; Udeagha and Breitenbach, 2023).

The agricultural sector and other natural resources are still endowment factors in UMI countries, for example, Samoa has endowment factors in the form of agriculture and fisheries which can improve its economy, Brazil has been crowned as the country with the fifth largest land area in the world which of course has an endowment factor in the agricultural sector, Gabon has endowment factors in the form of natural resources, namely wood, manganese, natural gas and crude oil, Libya has an endowment factor in the form of hydrocarbon natural resources, South Africa has an endowment factor for various minerals such as gems, gold, iron ore and uranium, and Venezuela has an endowment factor in the form of crude oil. Neo Malthusian Pessimistic Perspective explains the limitations of planet Earth (Katar and Anil, 2007). There are ecological and natural limits to economic growth. Earth has the nature of being limited, closed, and does not grow. It means that humans cannot carry out global trade by increasing the production of goods and services using natural resources and throwing away the waste produced in the production process into the biosphere forever (Katar and Anil, 2007). Subair (2015) states that Malthusian pessimism explains the earth has limitations which, if continuously exploited for global trade, will pose a major threat to humanity. It could be in the form of climate change which will cause increased carbon dioxide and global warming. Of the above explanation, the trade openness in UMI countries has a negative influence on environmental quality. This can be seen in Figure 2 that increasing trade openness in Upper Middle Income countries also increases carbon dioxide emission levels.



Note: RHS is the right side
Source: World Bank, 2023

Figure 2. Trade Openness and Carbon Dioxide Emissions in Upper Middle Income Countries (%)

The Pollution Haven Hypothesis explains that pollution from dirty industries could shift from high-income developed countries to UMI countries by taking advantage of cheaper labor and less stringent environmental regulations (Antweiler and Taylor, 2001; Cole, 2004; Miniesy, 2019; Udeagha and Breitenbach, 2023). In line with the Material Balance Model Theory, in the production process in a country, the energy produced does not consume all the products. However, residual waste remains. This waste will return to the environment. It indicates that trade openness has a negative effect on environmental quality (Ebert, 2007).

The IPAT theory (Impacts of Population, Affluence, and Technology) explains that when economic growth in a UMI country has successfully increased, clean production using technological innovation will follow so that environmental quality can be improved (Veli, 2022; Emma 2023). Technology will have a positive influence on environmental quality in developing countries. In this theory, it is explained that technology is a positive influence on environmental quality. One proxy for measuring technology is Information and Communication Technology (ICT). Generally, waste and toxic emissions occur during the production and processing of ICT equipment (Yohanie et al., 2023; Fitriana & Waswa, 2024; Malmodin et al, 2024; Zakiyah, Boonma, & Collado, 2024). More precisely, the use of advanced ICT equipment consumes high amounts of energy during installation and operation (Martinot, 2022; Isaac et al., 2022; Dessi & Shah, 2023; Habibi, Jiyane, & Ozsen, 2024; Helida, Ching, & Oyewo, 2023). The rapid growth of ICT which uses more energy leads to increased CO2 emissions. This can be seen in table 1.1 in the third decade, namely over 2010 to 2019, the use of ICT was 6.64% and produced 30.02% of carbon dioxide in UMI countries.

Apart from the previously mentioned variables, the income variable also influences environmental quality. Stern (2004) puts forward the Environmental Kuznet Curve (EKC) hypothesis, which is an inverted U relationship between environmental degradation and per capita income. It is a situation where the level of pollution will get worse until at a certain point there is an improvement in environmental quality in line with an increase in income levels. A research conducted by Azam and Khan (2016) found that when income levels are taken into account, the EKC hypothesis only applies to low- and lower-middle-income countries between 1975 and 2014. Additionally, Akca (2021) found that the increase in income that is in line with the EKC only occurs in middle-income countries where increasing per capita income plays an important role in pollution mitigation, so the curve is inverted U-shaped.

Human Development Index is an index measured from life expectancy, education and per capita income (Rangel, 2021; Matthew, 2023). A higher human development index in a country is obtained when the level of living, education, learning and per capita are higher. A knowledgeable workforce is considered to have accreditation within the human resources framework. Human resources have an important role in a country's economy, so that developed countries carry out a transformation from a labor-based economy to a knowledge-based economy (Akbar, 2021; Mizian, 2023; Sari, Omeiza, &

Mwakifuna, 2023; Saputro et al., 2023). In their research, Sinha and Sen (2016) found that HDI influences the increase in the global problem of CO2 emissions. Pirlogea (2012) explains that energy consumption in increasing CO2 emissions with HDI is directly correlated.

The urgency of this research lies in the continued increase in carbon dioxide emissions in Upper Middle Income countries every year. This can be caused by several factors. The reduction of environmental problems through technological means or economic means such as the increase in fuel prices, the introduction of taxes to limit the consumption of fossil fuels are the two main ways given by previous studies. However, these policies and innovations may have growth consequences even though they can reduce environmental problems. A possible potential solution is to be able to regulate factors that may affect environmental degradation. However, this can only be done if there is an established relationship between the influencing factors. Based on the background explanation above, this research intends to analyze further in the short and long term. This study aims to analyze the influence of trade openness, ICT, per capita income, and the Human Development Index on environmental quality in Upper-Middle Income countries in the short- and long-term and how per capita income influences environmental quality in the U.S. -shaped EKC hypothesis in Upper-Middle Countries over the period 1990-2020.

RESEARCH METHOD

The data in this research were derived from publications on the official website. In details, the data on carbon dioxide emissions, trade openness, ICT, per capita income were obtained from World Bank publications. Meanwhile, HDI data were obtained from United Nations Development Program (UNDP) publications. All belonged to panel data in the period of 1990 to 2020. In addition, the countries selected in this research were those classified as Upper-Middle Income countries from 1990 to 2020, including American Samoa, Brazil, Gabon, Libya, Mexico, South Africa and Venezuela.

Table 2. Definition of Research Variables

Variables	Symbol	Definition	Unit
Environmental Degradation	CO2	Emissions come from burning fossil fuels and making cement. This includes carbon dioxide produced during the consumption of solid, liquid and gaseous fuels as well as the combustion of gas.	*Metric tons per capita*
Trade Openness	TO	The amount of exports and imports of goods and services measured as a share of gross domestic product.	Percent USD
Information and Communication ICT	ICT	Proxy ICT service exports. Exports of information and communication ICT services include computer and communication services (telecommunications, postal and courier services) and information services (service transactions related to computer data and news).	*(% of service exports, BoP)*
Income per capita	Y	Gross domestic product divided by population at mid-year	USD
Human Development Index	HDI	A combination of various types of indicators, each of which includes life expectancy, education and per capita income.	Percent

The main forces of economic development are trade and energy use so that environmental pollution can be defined as the end product of energy consumption in relation to trade and economic growth. According to findings in the research by (Pervaiz et al, 2021), increasing HDI will help reduce greenhouse gas emissions or energy consumption in the long-term. This means that increasing HDI levels can increase the likelihood of strengthening environmental regulations. Based on the research above, the empirical model in this research was as follows:

$$CO_{2it}=f\ (TO, TIK, Y, Y^2, HDI) \qquad (1)$$

Trade openness in this research was written as TO. Trade openness is the amount of exports and imports of goods and services measured as a share of gross domestic product. Variables Y and Y2 are per capita income and the square of per capita income to test the EKC hypothesis. Then the above equation is written as follows:

$CO_{2it}=\alpha_0 + \alpha_1 TO_{it} + \alpha_2 TIK_{it} + \alpha_3 Y_{it}, + \alpha_4 Y^2{}_{it}, + \alpha_5 HDI_{it}, + \varepsilon_{it}$ ………………………….. (2)

The coefficients α1, α2, α3, and α5 showed the elasticity of environmental quality on trade openness, ICT, per capita income, and human capital. The normal or stochastic error term ε is assumed to be normally distributed. If α1 > 0, it means trade openness ($\alpha_4 TO_{it}$) is a substitute for environmental quality (), meaning that if UMI's trade openness increases, it will cause carbon dioxide emissions in the atmosphere to also increase and environmental quality will decrease. On the other hand, if $CO_{2it}\alpha 1 < 0$, it means that when UMI trade openness increases, this will improve environmental quality because it will reduce carbon dioxide emissions.

The data analysis technique used in this research was a panel *Vector Error Correction Model* (VECM). It is a data analysis method used for variables that are interdependent or often called cointegrated.

The standard form of the VECM system is as follows:

Xt=β0 + βnXt-n + et …………………………………………………….……………… (3)

From the explanation above, the form of the VECM model in this research was as follows:

$\Delta CO2it = \alpha 0 + \sum_{i=0}^{m} \alpha_{1i}\Delta CO2_{t-1} + \sum_{i=0}^{m} \alpha_{2i}\Delta TO_{t-1} + \sum_{i=0}^{m} \alpha_{3i}\Delta Tech_{t-1} + \sum_{i=0}^{m} \alpha_{4i}\Delta Y_{t-1}$
$+\sum_{i=0}^{m} \alpha_{5i}\Delta Y2_{t-1} + \sum_{i=0}^{m} \alpha_{6i}\Delta HDI_{t-1} + \alpha_7 ECT_{t-1}\ \varepsilon_t$ ……...……………………..........…….. (4)

Information :

CO2	= Carbon Dioxide Emissions
TO	= Trade Openness
Tech	= ICT
Y	= Income per capita
Y2	= Square Income per capita
HDI	= *Human Development Index*
ECT	= *Error Correction Term*in VECM
$\alpha_1,\alpha_2,\alpha_3,\alpha_4,\alpha_5,\alpha_6$	= Coefficient
μit	= Province specific effects
φt	= Time specific effect
ε_{it}	= Error

The forecasting analysis used in VECM is impulse response analysis (IRF) and variance decomposition. IRF analysis aims to see the effect of each variable when the shock is given. Variance decomposition is used to predict the contribution of each variable resulting from changes in certain variables in a system. Additional analysis to find out how accurate the forecasting results of a model are the Mean Absolute Percentage Error ($MAPE$) and Mean Square Error (MSE). The smaller the MSE and MAPE values, the more accurate the forecast results obtained.

The coefficient expected to form an EKC curve in accordance with the Kuznets hypothesis is positive at Yt and negative at Yt2 so that an inverted U curve will be formed. The formula for finding the turning point is as follows:

a. If α2 and β2 < 0 then an inverted U-shaped relationship occurs.
b. If α2 and β2 > 0 then a U-shaped relationship occurs

Turning point = - and $-\frac{\alpha 1}{2\alpha 2}\frac{\beta 1}{2\beta 2}$

RESULTS AND DISCUSSION

Unit Root Test aims to verify that the data generation process is stationary to avoid false regressions (Greene and William, 2003). Before carrying out VECM testing on short-term and long-term equations, a Unit Root Test is carried out. If the Unit Root Test value is greater than the significance level of 1%, 5% and 10%, the data are said stationary (Gujarati and Porter, 2012). Based on Table 3, it can be seen that not all of the research variables in the Unit Root Test at level level were stationary. Thus, it was necessary to continue with the Unit Root Test at the first difference level, namely by carrying out a root test at the first degree level or difference 1. In the first difference test, it was known that all variables were stationary indicated by a probability value of less than 1%, 5% and 10%.

Table 3. Unit Root Test

Method	Common Unit Root Process		Individual Unit Root Process		
	LLC	Breitung	IPS-W	ADF Fisher	PP Fisher
Levels					
CO2	1,0000	0.0000	0.5032	0.7578	*0.0032
TO	*0.0000	*0.0000	*0.0000	*0.0000	*0.0000
Q	0.4204	1,0000	**0.0263	***0.0781	0.2031
Y	1,0000	1,0000	0.999	1,0000	0.9977
Y2	0.954	1,0000	0.9764	0.9987	0.9779
HDI	0.3956	0.1246	0.8413	0.9685	0.9457
First Difference					
CO2	1,0000	1,0000	*0.0002	*0.0012	*0.0000
TO	0.255	0.9999	*0.0000	*0.0000	*0.0000
Q	0.8538	1,0000	*0.0000	*0.0000	1,0000
Y	1,0000	0.3808	***0.0898	0.2112	*0.0000
Y2	1,0000	0.9904	0.7600	0.9346	*0.0000
HDI	*0.0017	*0.0000	*0.0000	*0.0000	*0.0000

Description: *significant at 1% level
**significant at 5% level
*** significant at 10% level
Source: Data processed, 2024

The cointegration test is a test of to determine whether there is a long-term relationship between the independent variable and the dependent variable. It functions to find out whether the residuals are integrated or not (Gujarati and Porter, 2012). If these variables are integrated, it means there is a long-term relationship. Therefore, before carrying out the cointegration test, a regression must be carried out on the long-term equation to obtain the residual value. The cointegration test in this research used the Johansen Fisher's panel cointegration. It has two parts, namely trace and max eigenvalue test. In Table 4, the test showed a probability value of 0.0001 smaller than the significance of 0.01, indicating Ho was rejected or no cointegration occurred so that the equation being tested had a long-term equilibrium relationship and can be continued for VECM panel regression.

Table 4. Cointegration Test

Hypothesized No. of CE(s)	Fisher Statistics (from Trace Test)	Prob.	Fisher Statistics (from Max-Eigen Test)	Prob.
None *	95.75366	*0.0001	40.07757	*0.0001
At most 1*	69.81889	*0.0001	33.87687	*0.0001
At most 2*	47.85613	*0.0001	27.58434	*0.0001
At most 3*	29.79707	*0.0001	21.13162	*0.0000
At most 4*	15.49471	*0.0000	14.26460	*0.0000
At most 5*	3.841466	*0.0000	3.841466	*0.0000

Description: *significant at 1% level
Source: Data processed, 2024

An important procedure in estimating the VECM equation is selecting the optimum lag. The optimum lag selection procedure in VECM can use information criteria, namelyAICAndSC. In Table 5 it can be seen that lag 2 has a value AIC smallest and value SC smallest. Thus, lag 2 was used for the VECM parameter estimation process.

Table 5. Information Criteria

Lag	AIC	S.C
0	45.42016	45.52051
1	43.50347	44.20592
2	41.02713*	42.33169*

Source: Data processed, 2024

The results of the VECM Granger causality test panel are as follows table 6.

Table 6. VECM Panel Results

Dependent Variabels	Independent Variabels						
	CO2	TO	TIK	Y	Y^2	HDI	ECT-1
	Short Run						Long Run
CO2	-0,000924 (0,16588)	76,51542 (6,39475)	10,46582 (7,15982)	1207,087 (395,474)	-4044130 (189025)	0,349735*** (0,08063)	1,0000
TO	0,001256* (0,00130)	1,209455*** (0,05008)	-0,11914*** (0,05607)	-1,854785 (3,09699)	-33483,71 (14802,7)	-0,000563* (0,00063)	0,017593* (0,00020)
TIK	-0,009877* (0,00294)	-1,373792 (0,11321)	-0,360704 (0,12676)	-22,21550 (7,00152)	-126632,0 (33465,3)	0,002081* (0,00143)	-0,004906* (0,00074)
Y	0,000571 (6,8E-05)	-0,006854* (0,00263)	-0,010705* (0,00294)	-0,180789 (0,16263)	2522,167 (777,340)	4,22E-05 (3,3E-05)	0,000431 (9,7E-06)
Y^2	-1,38E-07 (1,2E-08)	2,67E-06 (4,5E-07)	-2,05E-06 (5,0E-07)	-5,23E-05 (2,8E-05)	-1,054071 (0,13259)	-6,37E-10 (5,7E-09)	-7,93E-08 (2,3E-09)
HDI	-0,702977 (0,26512)	-266,3344 (10,2206)	-7,216741 (11,4433)	2295,401 (632,076)	14530017 (3021139)	-0,557719 (0,12888)	2,77165*** (0,05168)

There is a condition of an inverted Kuznets U curve with a turning point:

a. Short term: US$ 728,530
b. Long term: US$ 772,839

Source: Data processed, 2024
Description : *significant at 1% level
**significant at 5% level
***significant at the 10% level

The relationship between trade openness and environmental quality in UMI countries can be seen in table 6. It showed that the long-term and short-term coefficient of trade openness on environmental quality was positive and statistically significant at the 1% level. This one is in line with findings by Sohag et al (2017); Khan (2017); Isik (2019); Ansari and Khan (2021); Islam (2023). In the short-term, greater openness to trade can encourage commercial access to cleaner technologies, thereby reducing CO2 emissions and atmospheric pollution as a result of which environmental quality will improve (Brack, 2019; Chhabra et al, 2023). Therefore, by comparing long-term and short-term estimates, the trade openness relationship depends on whether the movement was temporary or permanent.

Information and communication technology has a positive influence on environmental quality in the short term and a negative influence in the long term (Islam, 2023; Khan, 2023). According to Danish (2018) ICT is one of the biggest drivers of economic growth in the world. The latest study conducted by Godil et al. (2020), Magazzino et al. (2021) explained that ICT has a negative impact on the environment due to energy consumption during the production process. Even though ICT is an important stimulator for a country's economic growth, if the production factors used still produce carbon emissions, it will cause environmental degradation (Godil et al., 2020).

The effect of per capita income on carbon dioxide emissions in this study is positive in the short and long term. This means that increasing per capita income will increase carbon dioxide emissions so that environmental quality will decrease. The same thing was also stated by Farhani et al. (2014) regarding the positive influence of per capita income on carbon dioxide emissions in UMI countries due to the technology used being not environmentally friendly. The short-term and long-term regression results seen in Table 6 show the existence of the EKC hypothesis's inverted U relationship in the long- and short-term in UMI countries. This can be seen from the coefficient of per capita income and the square of per capita income which is negative. This is because UMI countries have an initial and final stage of development. Specifically, initially CO2 emissions will increase along with an increase in per capita income, but at the end of development when they reach a turning point UMI countries will reduce CO2 emissions along with an increase in per capita income. In this research, the turning point for UMI countries in the short-term was US$ 728,530 and in the long-term was US$ 772,839.

The Human Development Index in this research has a positive influence on environmental quality in UMI countries in the short and long term (Jahanger et al., 2023; Jens, 2024). The reason why HDI has a positive influence on the environment is because people who have higher education will be more productive and innovative. This will lead to the creation of new innovations and doing things in a better way (Afzal and Songseng 2021). In environmental sustainability, HDI has an important role, because public understanding of climate change can create mitigation actions (Ahmed and Wang, 2019; Assa, 2021). Through education, society can be more responsible for environmental sustainability (Yao et al., 2020) and people who have high education and income will be more responsible in protecting the environment compared to people who have low education and income.

After finding the best panel VECM (PVECM) model, the next step was to determine the forecasting and analysis of the forecasting structure of the model PVECM. Structural analysis includes Impulse-Response analysis and variance decomposition. Impulse-response analysis can use the impulse-response function (IRF The plot results of the IRF can be seen in Figure 3. For the next ten quarters, it can be seen that there are nine IRF plots which visually explain the response of a variable arising from a shock of 1 standard deviation either from itself or other variables.

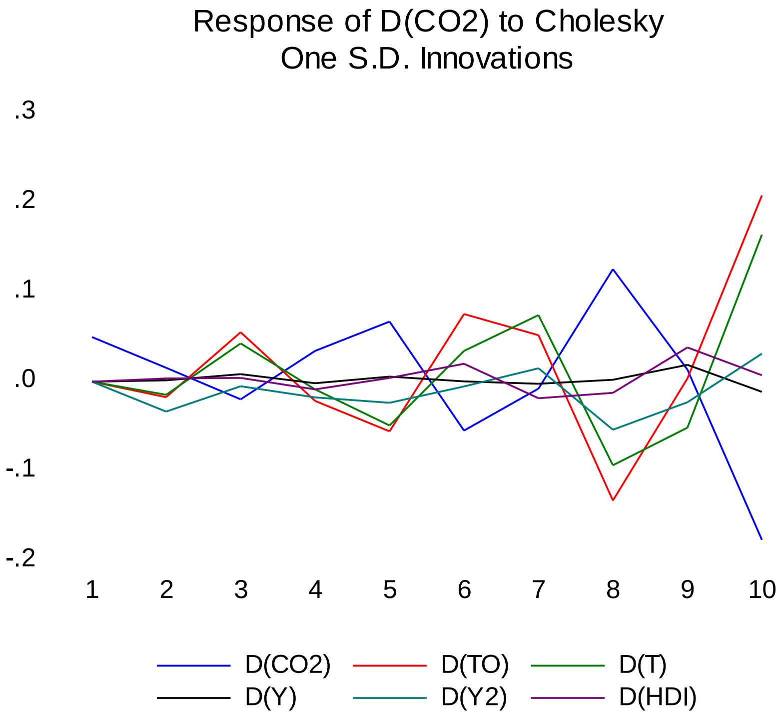


Figure 3. Impulse-Response Analysis

The results of quantitative IRF analysis for the next ten years can be seen in the following:

Table 7. Quantitative Impulse Response Function Analysis Results

Tahun	D(CO2)	D(TO)	D(ICT)	D(Y)	D(Y2)	D(HDI)
1	0.049996	0.000000	0.000000	0.000000	0.000000	0.000000
2	0.015423	-0.017241	-0.014554	0.001653	-0.033516	0.003754
3	-0.019780	0.055119	0.042660	0.008487	-0.005174	0.004327
4	0.034215	-0.021573	-0.008585	-0.001783	-0.017425	-0.008770
5	0.067225	-0.055390	-0.048920	0.005655	-0.023440	0.004201
6	-0.054461	0.075399	0.034433	0.000238	-0.005320	0.019872
7	-0.007730	0.051879	0.074394	-0.002345	0.014808	-0.018588
8	0.125752	-0.132641	-0.093250	0.002192	-0.053810	-0.012617
9	0.013572	0.003465	-0.051394	0.018759	-0.023075	0.038214
10	-0.176547	0.207995	0.164151	-0.011197	0.031287	0.007127

Based on Figure 3. and Table 7. it shows that the response of environmental degradation due to shocks that occur in trade openness is positive from the first period to the last period but four times has a negative response to trade openness shocks. This means that a one per cent shock to trade openness will react positively on environmental degradation in UMI countries. In particular, an increase in trade openness can lead to environmental degradation worldwide, but this depends on the income level of a country. Trade openness adversely affects the environment in middle- and low-income countries, but has a benign impact in high-income countries (Pham and Hoai, 2023). In the fourth and fifth years, the response of environmental degradation due to shocks in trade openness is negative and negative again in the eighth year. This indicates that if there is an increase in trade openness, it will reduce environmental degradation in UMI countries by 0.132641 metric tons per capita. This means that it is possible that trade openness in the future will have a positive impact on the environment in UMI countries.

Technology, Information and Communication (ICT) shocks are not much different from trade openness. ICT shocks that occur in years 2, 4, 5, 8, and 9 give a negative response to environmental degradation in UMI countries. This indicates that a one per cent increase in ICT will reduce environmental degradation by 0.051394 metric tons per capita in the ninth year. The causality of ICT on environmental degradation can be explained by IPAT. This theory states that technological advances, such as ICT, can lead to more efficient and less resource-intensive production processes, thereby reducing environmental impacts (Mol and Spaargaren, 2000; Asrial et al., 2024; Baah, Konovalov, & Tenzin, 2024). A one per cent increase in ICT responds negatively by reducing environmental degradation by 0.051394 metric tons per capita in UMI countries in the ninth year.

The EKC hypothesis in UMI countries still holds for the next ten years except in the seventh and tenth years because the coefficient of income per capita squared is positive while the coefficient of income per capita is negative. Based on the analysis, the seventh and tenth years will have a U-curve-like pattern, which is the opposite of the EKC curve. UMI countries initially when per capita income increases by 1%, environmental degradation will decrease by 0.011197% (ceteris paribus) until it finally reaches a certain minimum point at the turning point which is the beginning of the relationship between per capita income and environmental degradation, then it will return to being directly proportional. A 1% increase in per capita income further increases environmental degradation by 0.031287% (ceteris paribus) in the tenth year. Human Development Index (HDI) shocks to environmental degradation respond negatively in the fourth, seventh, and eighth years. This indicates that a one per cent increase in HDI responds negatively by reducing environmental degradation by 0.012617 metric tons per capita in UMI countries in the eighth year.

Variance decomposition analysis is often referred to as forecast error decomposition variance (FEDV) analysis. Conducting analysis using VD aims to predict the contribution of the percentage role of each variable due to changes in certain variables in the VECM model, although it is generally known that the biggest shock that affects the diversity of each variable is the shock that comes from itself. In this study, the use of VD analysis aims to obtain an overview of the influence of the development of trade openness variables, ICT, per capita income, and HDI on environmental degradation. The results of E-views output showing the influence of the four variables, as shown in Table 8. informs that the largest contribution that affects the variability in the environmental degradation variable is the shock originating from environmental degradation itself.

Table 8. Carbon dioxide variance decomposition

Period	CO_2	TO	TIK	Y	Y^2	HDI
1	100.0000	0.000000	0.000000	0.000000	0.000000	0.000000
2	62.40463	6.776288	4.828801	0.062320	25.60665	0.321312
3	32.07850	34.19612	20.83098	0.766567	11.79136	0.336468
4	36.29141	32.08172	17.77200	0.657943	12.27064	0.926285
5	39.32216	30.62808	20.05954	0.490139	8.932076	0.567998
6	36.05368	38.40672	17.39033	0.336464	6.214989	1.597821
7	28.51164	36.69808	27.00549	0.277978	5.417894	2.088922
8	31.89922	37.87434	22.96790	0.138726	5.935361	1.184459
9	30.30062	35.75136	24.54717	0.513884	6.180091	2.706880
10	30.35271	39.14896	25.46114	0.307363	3.424361	1.305466

Similar to forecasting analysis in general, to determine the accuracy of forecast results from a model, the Mean Absolute Percentage Error ($MAPE$) and Mean Square Error (MSE) can be used.

Table 9. Accuracy of forecast results

Variables	MSE	MAPE
CO2	1.387765	101.1075
TO	8.048700	935.0379
Q	49.67192	121.2725
Y	316.7823	178.2234
Y2	1246036.	81811.93
HDI	5911385.	100,0000

In Table 9. it can be seen that the smallest values of MSE and $MAPE$ were obtained by the variable trade openness and carbon dioxide emissions. It implied that forecasting using the P model $VECM$lag 2 was more accurate when applied totrade openness and carbon dioxide emissions. The effect of trade openness on environmental degradation in UMI countries in this study is positive both in the short and long run. The proxy used to measure environmental degradation in this study is carbon dioxide. The positive effect here means that an increase in trade openness results in an increase in environmental degradation in UMI countries in the short and long term (Lv, 2019).

In the contemporary global landscape, trade openness is an important driver of economic growth, encouraging international co-operation and economic development (Grossman and Helpman, 1991). However, during this economic progress, the complex relationship between trade and environmental sustainability, particularly in terms of environmental degradation, has become a major concern for scientists. In an era characterised by the urgent need for global environmental sustainability and amidst discussions around climate change mitigation, the relationship between trade openness and environmental degradation has become a particularly important area of inquiry. This dynamic relationship draws on rich economic and environmental theories and explains the multifaceted mechanisms through which trade affects environmental degradation. Trade is a driver of economic growth and globalisation but also has environmental consequences (Grossman and Helpman, 1991; Alsamara et al., 2022).

At its core, trade can serve as an engine of economic growth that leads to increased per capita income and the expansion of energy-intensive production processes. This phenomenon is known as the "scale effect," often accompanied by increased energy consumption and increased CO2 emissions (Copeland & Taylor, 2004). Furthermore, trade can have "composition effects" as it alters global production and consumption patterns, leading to the production of emission-intensive goods. In addition, the Pollution Haven Hypothesis adds another layer of complexity by suggesting that countries with less stringent environmental regulations may specialise in pollution-intensive industries when faced with differences in standards. Typically, such industries are capital-intensive in developed countries with strict environmental policies, and large capital may shift pollution-intensive production to developing countries. This results in developing countries experiencing an environmental consumption burden compared to developed countries (Levinson, 2008; Ansari and Khan, 2021).

The relationship between ICT and environmental degradation has a significant effect at the 1% level positively in the short term and negatively in the long term. If the value of ICT increases, it will also increase environmental degradation in UMI countries in the short term and will reduce environmental degradation in the long term. In the short run, an increase in ICT will increase environmental degradation in UMI countries. This happens because of the inefficient use of energy in technological equipment. Li (2023) in their research used internet usage to measure technology variables. In their study, the internet significantly contributed to carbon emissions in Belgium, Bulgaria, Finland, and Poland. Lee. Brahmasrene (2014) found that 1% of telecommunication technology will increase 0.66% of carbon emissions in ASEAN countries.

Asongu et al (2017) in their research showed that environmental quality in Sub-Saharan Africa decreases monotonically with an increase in the penetration of information and communication technology. The increasing penetration of information and communication technology in Sub-Saharan Africa coupled with the inefficient use of energy and the heavy dependence of certain countries on fossil fuels for electricity caused the environmental quality in Sub-Saharan Africa to deteriorate.

The short and long-run regression results indicate the existence of an inverted-U relationship of the EKC hypothesis in the long and short run in the UMI countries. In the short term, initially when the level of income per capita increases by 1 US$, environmental degradation increases, until it finally reaches a maximum point at the income level of US$ 2,071,174 in lag 1 and US$ 3,565,415 in lag 2. Furthermore, the relationship between income per capita and CO2 emissions per capita will be inversely proportional, so that an increase in economic growth by 1 US$ actually reduces the level of CO2 emissions per capita by 1.38 and 1.53 metric tons per capita (ceteris paribus). The EKC hypothesis in UMI countries still holds for the next ten years except in the seventh and tenth years. Based on the analysis, the seventh and tenth years will be patterned after the U-curve, which is the opposite of the EKC curve. UMI countries initially when per capita income increases by 1%, environmental degradation will decrease by 0.011197% (ceteris paribus) until it finally reaches a certain minimum point at the turning point which is the beginning of the relationship between per capita income and environmental degradation, then it will return to being directly proportional. A 1% increase in per capita income further increases environmental degradation by 0.031287% (ceteris paribus) in the tenth year. Shafik (1994) conducted an empirical study on the relationship between economic development and environmental performance with a large number of long-term national samples. Environmental degradation is one of the earliest environmental problems that need to be addressed because the associated costs are relatively low. Middle-income countries can easily bear the economic costs of environmental improvement in most countries require environmental policies and investments to reduce environmental degradation. Existing literature reveals that although many previous theoretical and empirical studies focused on verifying the EKC. Almost all of these studies started in 1992, which yielded mixed results, with some studies validating and some failing to confirm the existence of EKC. For instance, Moomaw and Unruh (1997) conducted an empirical study to test the validity of EKC in 16 European countries over the period 1950-1973 and 1974-1992. The study revealed that neither U- nor N-shaped relationships between CO2 emissions and income provide a consistent picture of future behaviour.

Human Development Index (HDI) in this study has a negative influence in the short and long term on environmental degradation. This means that if HDI increases by 1%, it will reduce environmental degradation in the long and short term. Human development is important in this case because those with higher education are believed to be more productive, responsible and innovative, leading to the creation of new ideas and better ways of doing things (UNESCO, 2010; Ahmed et al., 2020a, Ahmed et al., 2020b; Afzal and Songseng 2021; Moo et al, 2024; Hidayati et al, 2024; Yadewani et al, 2024). In the field of environmental sustainability, human development is also important and useful, as human understanding of the environment, climate change and its consequences is crucial in any form of mitigation action (Bano et al., 2018; Ahmed and Wang, 2019; Assa, 2021; Asrial et al., 2023; Apeadido et al., 2024).

The outcomes of this study have considerable Policy implication regarding trade openness policy formulation to reduce environmental degradation especilly in Upper Middle Income Countries. The Upper Middle Income countries used as an observation in this study are countries that are consistently classified as upper middle income countries from 1990 to 2020. This is done because in order to maintain the consistency of the measurement of Upper Middle Income countries. So that this leads to limited research because other countries that are already classified as upper-middle-income countries have not been included in the calculation. The period used in this research is from 1990 to 2020. This is because it uses the available data when this study was carried out, so it needs a new period of year that can describe the current condition. The limitation of this research are data analysis techniques use the VECM panel that predicts the short-term and long-term relationship between trade openness, ICT, per capita income, and HDI to environmental degradation. Research results explain the linear relationship between trade openness, ICT and HDI to environmental degradation does not explain a nonlinear or quadratic relationship. The next research can prove the relationship of these variables nonlinearly such as the research conducted by Anon et al (2017), Asongu (2017) and Mk et al (2021) in discussing the influence of ICT on environmental degradation.

Regarding the findings, UMI countries are advised to remove tariffs and other trade barriers for producing environmentally friendly goods so that they will be able to increase green innovation at lower costs. The economies of UMI countries must develop and enforce efficient laws and policies to prevent or reduce environmental pollution while supporting sustainable growth. The governments of UMI countries should encourage companies to use environmentally friendly technologies for ICT production, as well as switch from short life cycle products and conventional technological equipment to more modern technologies. In addition, UMI countries are advised to reduce health service costs but also improve the quality of life of their citizens as reflected in the Human Development Index.

CONCLUSION

The aim of this research was to analyze the influence of trade openness, ICT, per capita income, and the Human Development Index on environmental quality in Upper-Middle Income countries in the short- and long-term and how per capita income influenced environmental quality in the U-shaped EKC hypothesis in countries Upper-Middle Income over the period of 1990-2020. According to the findings, several conclusions are drawn as follows. The coefficient of trade openness in the long-term and short term on environmental quality is positive and statistically significant at the 1% level. The relationship between ICT and environmental quality has a positive influence in the short-term and a negative influence in the long-term. The relationship between per capita income and environmental quality has a positive influence in the long- and short-term. Here, an increase in per capita income will increase carbon dioxide which causes a decrease in environmental quality and shows the existence of an inverted U relationship in the long and short term of the EKC hypothesis in UMI countries with the turning point in the short term being US$ 728,530 and in the long term being US$ 772,839. Finally, the Human Development Index in this research has a positive influence in the short and long term on environmental quality.

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AUTHOR CONTRIBUTIONS

Author 1-2 creates articles and creates instruments and is responsible for research.

CONFLICTS OF INTEREST

The author(s) declare no conflict of interest.

REFERENCES

Amaliah, I. D. (2022). The effect of village original income, village allocation of funds, tax sharing and retribution on village expenditures. *Accounting and Sustainability, 1*(1), 1-8. https://doi.org/10.58968/as.v1i1.254.

Akbar, M., Hussain, A., Akbar, A., & Ullah, I. (2021). The dynamic association between healthcare spending, CO 2 emissions, and human development index in OECD countries: Evidence from panel VAR model. *Environment, development and sustainability*, *23*, 10470-10489. https://doi.org/10.1007/s10668-020-01066-5.

Akca, H. (2021). Environmental Kuznets Curve and financial development in Turkey: evidence from augmented ARDL approach. *Environmental Science and Pollution Research*, *28*(48), 69149-69159. https://doi.org/10.1007/s11356-021-15417-w.

Alsamara, I.; Beinert, S. F.; De Jong, J. C.; Klappe, M. J. P.; Marewski, V. S. (2022). (Policy brief). SEEJPH 2022, posted: 23 June 2022. https://doi.org/10.11576/seejph-5603.

Ansari, M. A., and Khan, N. A. (2021). Decomposing the trade-environment nexus for high income, upper and lower middle income countries: What do the composition, scale, and technique effect indicate? Ecological Indicators, 121(September 2020), 107122. https://doi.org/10.1016/j.ecolind.2020.107122.

Antweiler, W., Copeland, B. R., & Taylor, M. S. (2001). Is free trade good for the environment?. *American economic review*, *91*(4), 877-908. https://doi.org/10.1257/aer.91.4.877.

Apeadido, S., Opoku-Mensah, D., & Mensah, G. O. (2024). Enhancing science process skills and academic performance in biology: The impact of practical work. *Integrated Science Education Journal*, *5*(1), 34-41. https://doi.org/10.37251/isej.v5i1.854.

Appiah-Otoo, I., Acheampong, A. O., Song, N., & Chen, X. (2023). The impact of information and communication technology (ICT) on carbon dioxide emissions: Evidence from heterogeneous ICT countries. *Energy & Environment*, *34*(8), 3080-3102. https://doi.org/10.1177/0958305X221118877.

Asrial, A., Syahrial, S., Kurniawan, D. A., Aldila, F. T., & Iqbal, M. (2023). Implementation of web-based character assessment on students' character outcomes: A review on perception and gender. *JOTSE: Journal of Technology and Science Education*, *13*(1), 301-328. https://doi.org/10.3926/jotse.1564.

Asrial, A., Syahrial, S., Kurniawan, D. A., Putri, F. I., Perdana, R., Rahmi, R., Susbiyanto, S., & Aldila, F. T. (2024). E-Assessment for character evaluation in elementary schools. *Qubahan Academic Journal*, *4*(3), 806-822. https://doi.org/10.48161/qaj.v4n3a595.

Assa, J. (2021). Less is more: The implicit sustainability content of the human development index. *Ecological economics*, *185*, 107045. https://doi.org/10.1016/j.ecolecon.2021.107045.

Asongu, S. A., Le Roux, S., & Biekpe, N. (2017). Environmental degradation, ICT and inclusive development in Sub-Saharan Africa. *Energy Policy*, *111*, 353-361. https://doi.org/10.1016/j.enpol.2017.09.049.

Azam, M., & Khan, A. Q. (2016). Testing the Environmental Kuznets Curve hypothesis: A comparative empirical study for low, lower middle, upper middle and high income countries. *Renewable and Sustainable Energy Reviews*, *63*, 556-567. https://doi.org/10.1016/j.rser.2016.05.052.

Baah, R., Konovalov, O., & Tenzin, S. (2024). Effectiveness of e-assessment in science learning: Improving the quality and efficiency of assessment in the digital era. *Integrated Science Education Journal*, *5*(2), 74-81. https://doi.org/10.37251/isej.v5i2.960.

Brack, D. (2019). Trade and the environment. Trade Politics, Second Edition, January 2008, 1–330. https://doi.org/10.4324/9780429486722-19.

Chhabra, M., Giri, A. K., & Kumar, A. (2023). Do trade openness and institutional quality contribute to carbon emission reduction? Evidence from BRICS countries. *Environmental Science and Pollution Research*, *30*(17), 50986-51002. https://doi.org/10.1007/s11356-023-25789-w.

Cole, M. A. (2004). Trade, the pollution haven hypothesis and the environmental Kuznets curve: examining the linkages. *Ecological economics*, *48*(1), 71-81. https://doi.org/10.1016/j.ecolecon.2003.09.007.

Danish, Khan, N., Baloch, M. A., Saud, S., & Fatima, T. (2018). The effect of ICT on CO 2 emissions in emerging economies: does the level of income matters?. *Environmental Science and Pollution Research*, *25*, 22850-22860. https://doi.org/10.1007/s11356-018-2379-2.

Dessi, L. C., & Shah, M. (2023). Application of the numbered head together type cooperative learning model to improve student learning outcomes in mathematics subjects. *Interval: Indonesian Journal of Mathematical Education*, *1*(2), 67-72. https://doi.org/10.37251/ijome.v1i2.773.

Ebert, U., & Welsch, H. (2007). Environmental emissions and production economics: implications of the materials balance. *American Journal of Agricultural Economics*, *89*(2), 287-293. https://doi.org/10.1111/j.1467-8276.2007.00997.x.

Engström, E., & Kolk, M. (2024). Projecting environmental impacts with varying population, affluence and technology using IPAT–Climate change and land use scenarios. *Vienna Yearbook of Population Research*, *22*, 1-29. https://doi.org/10.1553/p-n5en-z38a.

Farhani, S., Mrizak, S., Chaibi, A., & Rault, C. (2014). The environmental Kuznets curve and sustainability: A panel data analysis. *Energy Policy*, *71*, 189-198. https://doi.org/10.1016/j.enpol.2014.04.030.

Fitriana, H., & Waswa, A. N. (2024). The influence of a realistic mathematics education approach on students' mathematical problem solving ability. *Interval: Indonesian Journal of Mathematical Education*, *2*(1), 29-35. https://doi.org/10.37251/ijome.v2i1.979.

Godil, D. I., Sharif, A., Afshan, S., Yousuf, A., & Khan, S. A. R. (2020). The asymmetric role of freight and passenger transportation in testing EKC in the US economy: evidence from QARDL approach. *Environmental Science and Pollution Research*, *27*, 30108-30117. https://doi.org/10.1007/s11356-020-09299-7.

Greene, William H. (2003). *Econometric Analysis, Fifth Edition*, New Jersey, Prentice-Hall

Gujarati, Damodar N. dan Dawn C. Porter. (2012). *Dasar-dasar Ekonometrika Buku 2. Edisi 5*. Raden Carlos Mangunsong (penj.). Jakarta: Salemba Empat

Grossman, G. M., Krueger, A. B., Brown, D., Evans, G., and Schoepfle, G. (1991). NBER WORKING PAPERS SERIES 1050 Massachusetts Avenue Jeff Mackie-Mason provided helpful comments and. Gene, 3914.

Habibi, M. W., Jiyane, L., & Ozsen, Z. (2024). Learning revolution: The positive impact of computer simulations on science achievement in madrasah ibtidaiyah. *Journal of Educational Technology and Learning Creativity*, *2*(1), 13-19. https://doi.org/10.37251/jetlc.v2i1.976.

Helida, Y., Ching, C. P., & Oyewo, A. (2023). Development of a simple stirling engine demonstration tool on the subject of thermodynamics. *Journal of Educational Technology and Learning Creativity*, *1*(2), 59-67. https://doi.org/10.37251/jetlc.v1i2.790.

Hidayati, A., Susanti, E., Jamalong, A., Ginting, D., Suwanto, W., & Arifin, A. (2024). Marketing analytics in the era of digital-based marketing strategy. *Jurnal Ilmiah Ilmu Terapan Universitas Jambi*, *8*(1), 61-75. https://doi.org/10.22437/jiituj.v8i1.31908.

Hossain, M. A., & Chen, S. (2021). Nexus between Human Development Index (HDI) and CO 2 emissions in a developing country: Decoupling study evidence from Bangladesh. *Environmental Science and Pollution Research*, *28*, 58742-58754. https://doi.org/10.1007/s11356-021-14822-5.

Isik, C., Ongan, S., & Ozdemir, D. (2019). Testing the EKC hypothesis for ten US states: An application of heterogeneous panel estimation method. *Environmental Science and Pollution Research*, *26*, 10846-10853. https://doi.org/10.1007/s11356-019-04514-6.

Islam, M. S., & Rahaman, S. H. (2023). The asymmetric effect of ICT on CO2 emissions in the context of an EKC framework in GCC countries: the role of energy consumption, energy intensity, trade, and financial development. *Environmental Science and Pollution Research*, *30*(31), 77729-77741. https://doi.org/10.1007/s11356-023-27590-1.

Islam, M. S., Rahaman, S. H., ur Rehman, A., & Khan, I. (2023). ICT's impact on CO2 emissions in GCC region: the relevance of energy use and financial development. *Energy Strategy Reviews*, *49*, 101147. https://doi.org/10.1016/j.esr.2023.101147.

Jahanger, A., Yang, B., Huang, W. C., Murshed, M., Usman, M., & Radulescu, M. (2023). Dynamic linkages between globalization, human capital, and carbon dioxide emissions: empirical evidence from developing economies. *Environment, development and sustainability*, *25*(9), 9307-9335. https://doi.org/10.1007/s10668-022-02437-w.

Malmodin, J., Lövehagen, N., Bergmark, P., & Lundén, D. (2024). ICT sector electricity consumption and greenhouse gas emissions–2020 outcome. *Telecommunications Policy*, *48*(3), 102701. https://doi.org/10.1016/j.telpol.2023.102701.

Mizian, Z. (2023). Development of an electronic brick bonding module using the autocad program for students. *Tekno-Pedagogi: Jurnal Teknologi Pendidikan*, *13*(2), 35-43. https://doi.org/10.22437/teknopedagogi.v13i2.32531.

Jorgenson, A., Schor, J., & Huang, X. (2017). Income inequality and carbon emissions in the United States: a state-level analysis, 1997–2012. *Ecological Economics*, *134*, 40-48. http://dx.doi.org/10.1016/j.ecolecon.2016.12.016.

Katar Singh, Anil Shishodia. (2007). *Environmental Economics: Theory and Applications*. SAGE Publications.

Khan, M. T. I., Yaseen, M. R., & Ali, Q. (2017). Dynamic relationship between financial development, energy consumption, trade and greenhouse gas: comparison of upper middle income countries from Asia, Europe, Africa and America. *Journal of cleaner production*, *161*, 567-580. https://doi.org/10.1016/j.jclepro.2017.05.129.

Kusuma, R. S. (2020). Improving students' basic asking skills by using the discovery learning model. *Tekno - Pedagogi : Jurnal Teknologi Pendidikan*, *10*(2), 8-13. https://doi.org/10.22437/teknopedagogi.v10i2.32743.

Levinson, A., & Taylor, M. S. (2008). Unmasking the pollution haven effect. *International economic review*, *49*(1), 223-254. https://doi.org/10.1111/j.1468-2354.2008.00478.x.

Li, Y., & Zhang, Y. (2023). What is the role of green ICT innovation in lowering carbon emissions in China? A provincial-level analysis. *Energy Economics*, *127*, 107112. https://doi.org/10.1016/j.eneco.2023.107112

Lv, Z., & Xu, T. (2019). Trade openness, urbanization and CO2 emissions: dynamic panel data analysis of middle-income countries. *The Journal of International Trade & Economic Development*, *28*(3), 317-330. https://doi.org/10.1080/09638199.2018.1534878.

Magazzino, C., Porrini, D., Fusco, G., & Schneider, N. (2021). Investigating the link among ICT, electricity consumption, air pollution, and economic growth in EU countries. *Energy Sources, Part B: Economics, Planning, and Policy*, *16*(11-12), 976-998. https://doi.org/10.1080/15567249.2020.1868622.

Martinot, E., Chaurey, A., Lew, D., Moreira, J. R., and Wamukonya, N. (2002). Renewable energy markets in developing countries. *Annual Review of Energy and the Environment, 27*, 309–348. https://doi.org/10.1146/annurev.energy.27.122001.083444.

Matthew Kahane, Józefina Hrynkiewicz, Jolanta Supinska, Irena Herbst, Andrzej Bratkowski, Malgorzata Pawlisz. (2003). *Human Development Report 2003: Millennium Development Goals: A Compact Among Nations to End Human Poverty*. New York.

Miniesy, R. S., & Tarek, M. (2019). Is there evidence of PHH in developing Asia?. *Journal of Chinese Economic and Foreign Trade Studies*, *12*(1), 20-39. https://doi.org/10.1108/JCEFTS-06-2018-0018.

Mo, N. T., Binh, N. T., Nhung, L. T., Hung, P. H., Cu, H. M., Linh, N. T., & Hai, T. V. (2024). Employee satisfaction, engagement and financial performance in stock brokerage companies. *Jurnal Ilmiah Ilmu Terapan Universitas Jambi*, *8*(1), 284-299. https://doi.org/10.22437/jiituj.v8i1.32199.

Moomaw, W. R., & Unruh, G. C. (1997). Are environmental Kuznets curves misleading us? The case of CO2 emissions. *Environment and development economics*, *2*(4), 451-463. https://doi.org/10.1017/S1355770X97000247.

Mujtaba, A., Jena, P. K., and Mukhopadhyay, D. (2020). Determinants of CO2 emissions in upper middle-income group countries: an empirical investigation. *Environmental Science and Pollution Research*, *27*(30), 37745–37759. https://doi.org/10.1007/s11356-020-09803-z.

Murshed, M. (2020). Are trade liberalization policies aligned with renewable energy transition in low and middle income countries? an instrumental variable approach. *Renewable Energy, 151*, 1110–1123. https://doi.org/10.1016/j.renene.2019.11.106.

Negro, S. O., Alkemade, F., and Hekkert, M. P. (2012). Why does renewable energy diffuse so slowly? A review of innovation system problems. *Renewable and Sustainable Energy Reviews, 16*(6), 3836–3846. https://doi.org/10.1016/j.rser.2012.03.043.

Pervaiz, R., Faisal, F., Rahman, S. U., Chander, R., & Ali, A. (2021). Do health expenditure and human development index matter in the carbon emission function for ensuring sustainable development? Evidence from the heterogeneous panel. *Air Quality, Atmosphere & Health*, *14*(11), 1773-1784. https://doi.org/10.1007/s11869-021-01052-4.

Pham Xuan Hoa, Vu Ngoc Xuan, Nguyen Thi Phuong Thu. (2023). Nexus of innovation, renewable consumption, FDI, growth and CO2 emissions: The case of Vietnam, *Journal of Open Innovation: Technology, Market, and Complexity, 9*(3) https://doi.org/10.1016/j.joitmc.2023.100100.

Pirlogea, C. (2012). The Human Development Relies on Energy. Panel Data Evidence. Procedia. Economics and finance, 3, 496-501. https://doi.org/10.1016/S2212-5671(12)00186-4

Rangel Chris Eko Bieth. (2021). The Influence of Gross Domestic Product and Human Development Index on CO2 Emissions. *Journal of Physics: Conference Series*. https://doi.org/10.1088/1742-6596/1808/1/012034.

Sari, R., Omeiza, I. I., & Mwakifuna, M. A. (2023). The influence of number dice games in improving early childhood mathematical logic in early childhood education. *Interval: Indonesian Journal of Mathematical Education*, *1*(2), 61-66. https://doi.org/10.37251/ijome.v1i2.776.

Saputro, H. D., Rustaminezhad, M. A., Amosa, A. A., & Jamebozorg, Z. (2023). Development of e-learning media using adobe flash program in a contextual learning model to improve students' learning outcomes in junior high school geographical research steps materials. *Journal of Educational Technology and Learning Creativity*, *1*(1), 25-32. https://doi.org/10.37251/jetlc.v1i1.621.

Shafik, N. (1994). Economic development and environmental quality: an econometric analysis. *Oxford economic papers*, *46*(Supplement_1), 757-773. https://doi.org/10.1093/oep/46.Supplement_1.757.

Shahbaz, M., Balsalobre, D., and Shahzad, S. J. H. (2019). The Influencing Factors of CO2 Emissions and the Role of Biomass Energy Consumption: Statistical Experience from G-7 Countries. *Environmental Modeling and Assessment*, *24*(2), 143–161. https://doi.org/10.1007/s10666-018-9620-8.

Sinha, A., and Sen, S. (2016). Atmospheric consequences of trade and human development: A case of BRIC countries. *Atmospheric Pollution Research, 7*, 980-989. https://doi.org/10.1016/j.apr.2016.06.003.

Sohag, K., Al Mamun, M., Uddin, G. S., and Ahmed, A. M. (2017). Sectoral output, energy use, and CO2 emission in middle-income countries. *Environmental Science and Pollution Research, 24*(10), 9754–9764. https://doi.org/10.1007/s11356-017-8599-z.

Stern David I. (2004). The Rise and Fall of the Environmental Kuznets Curve. World Development

Subair. (2015). The relevance of malthus' theory in discourse. *Journal Of Dialectics*, *9*(2), 96–110.

Suwarni, R. (2021). Analysis the process of observing class iv students in thematic learning in primary schools. *Tekno - Pedagogi : Jurnal Teknologi Pendidikan*, *11*(1), 26-32. https://doi.org/10.22437/teknopedagogi.v11i1.32717.

Temurshoev, U. (2006). Pollution Haven Hypothesis or Factor Endowment Hypothesis: Theory and Empirical Examination for the US and China. Economics, Environmental Science. https://doi.org/10.2139/ssrn.1147660.

Tiba, S., and Omri, A. (2017). Literature survey on the relationships between energy, environment and economic growth. *Renewable and Sustainable Energy Reviews, 69*(September), 1129–1146. https://doi.org/10.1016/j.rser.2016.09.113.

Udeagha, M.C., Breitenbach, M.C. (2023). On the asymmetric effects of trade openness on CO2 emissions in SADC with a nonlinear ARDL approach. *Discov Sustain 4*, 2. https://doi.org/10.1007/s43621-022-00117-3.

Veli Yilanci, Recep Ulucak, Yaoqi Zhang, Valeria Andreoni. (2022). The role of affluence, urbanization, and human capital for sustainable forest management in China: Robust findings from a new method of Fourier cointegration. Sustainable Development. https://doi.org/10.1002/sd.2421.

Yadewani, D., Pandi, O. D., Syafrani, S., Nurofik, A., & Poddar, S. (2024). Impact of government policies on the knowledge base of sustainable small and medium-sized enterprises. *Jurnal Ilmiah Ilmu Terapan Universitas Jambi*, *8*(1), 251-266. https://doi.org/10.22437/jiituj.v8i1.31884.

Yohanie, D. D., Botchway, G. A., Nkhwalume, A. A., & Arrazaki, M. (2023). Thinking process of mathematics education students in problem solving proof. *Interval: Indonesian Journal of Mathematical Education*, *1*(1), 24-29. https://doi.org/10.37251/ijome.v1i1.611.

Zakiyah, Z., Boonma , K., & Collado, R. (2024). Physics learning innovation: Song and animation-based media as a learning solution for mirrors and lenses for junior high school students. *Journal of Educational Technology and Learning Creativity*, *2*(2), 54-62. https://doi.org/10.37251/jetlc.v2i2.1062.