ISSN 2409-2665
Journal of Logistics, Informatics and Service Science
Vol. 12 (2025) No. 1, pp. 211-230
DOI:10.33168/JLISS.2025.0112

Exploring the Roles of Industrial Growth, Energy Use, Human Capital, and Technological Innovation in Driving Greenhouse Gas Emissions: Evidence from Vietnam

Lien Thi Hoa Do, Phuong Vo Hang Hoang

University of Labor and Social Affairs, Ho Chi Minh City Campus, Vietnam.
liendth@ldxh.edu.vn, phuonghvh@ldxh.edu.vn

Abstract. This study investigates the impacts of industrial growth, economic growth, energy consumption, human capital, and technological innovation on greenhouse gas emissions in Vietnam from 1986 to 2019. Using the Autoregressive Distributed Lag (ARDL) model and time-series data, the findings reveal that in the long run, industrial growth, population growth, fossil fuel consumption, and technological innovation positively influence greenhouse gas emissions.Conversely, human capital development plays a crucial role in reducing emissions. In the short run, economic growth, population growth, and technological innovation exhibit varying effects on emissions. The study underscores the importance of promoting human capital investment, industrial restructuring towards greener sectors, and adopting cleaner energy sources and technologies to mitigate greenhouse gas emissions while sustaining economic progress in Vietnam.

Keywords: greenhouse gas emissions, human capital, energy consumption, industrial growth.

1. Introduction

Climate change is predominantly attributed to the emission of greenhouse gases, with a global trend indicating an escalation in such emissions, potentially leading to perilous levels of climatic alterations (IPCC, 2014). Emissions of carbon dioxide have been unequivocally identified as a principal contaminant (Edoja et al., 2016), constituting approximately 75% of total greenhouse gas emissions (Abbasi & Riaz, 2016), thereby contributing significantly to climate change. The incessant augmentation in greenhouse gas emissions, primarily driven by CO2 emissions, necessitates an urgent investigation into the underlying causes. This, in turn, will facilitate the development of effective solutions which mitigated the adverse effects on the environment and ecosystems

The escalation of greenhouse gas emissions in Vietnam, which amplified fourfold from 2000 to 2015 (World Bank, 2022), is a matter of significant concern. If the current response policies are not fully implemented, Vietnam will ascend to the status of a major greenhouse gas emitter by 2030.Under the business-as-usual emissions scenario, it is anticipated that Vietnam's total annual emissions will experience nearly a fourfold increase over the period from 2010 to 2030. Carbon and energy intensity in Vietnam also remains high compared to international standards (Audinet et al., 2016).

Vietnam initiated a comprehensive economic reform and transition towards a market economy in 1986, leading to impressive economic growth. From 1986 to 2019, the Vietnamese economy experienced consistent growth with an average rate of about 6.8% per year. This was accompanied by a rapid increase in energy consumption, with an average rate of 9.9% per year, primarily non-renewable energy consumption. As a result, greenhouse gas emissions have rised at an average rate of 6.8% per year during the period of 1990 and 2019, mainly due to the rapid industrialization and high economic growth and the swift consumption of fossil fuel. Vietnam faced many difficulties and challenges while carrying out the task of socio-economic development in the context of many international and domestic advantages. Additionally, climate change, extreme weather, and natural disasters have increasingly become complex and unpredictable, negatively impacting production and social life. Vietnam has formulated and issued many critical policies related to responding to climate change at the national, local, and sectoral levels. The sustainable development index of Vietnam in 2020 has increased by 39 places compared to 2016, ranking 49th out of 166 countries and territories. The industrial sector has made substantial contributions to the country's socio-economic progress. The proportion of processing and manufacturing industries within the industrial structure has seen a significant increase. However, the sector faces numerous challenges, particularly its considerable reliance on natural fuels, which has caused to a surge in poisonous gas.

Mitigating greenhouse gas emissions is an increasingly pressing challenge for Vietnam's sustainable development. However, so far, no research has been conducted that simultaneously evaluates the impact of industrial growth, economic growth, and energy consumption, along with the role of human capital and technological innovation on greenhouse gas emissions in Vietnam. Consequently, the research was conducted with the goal of adding more empirical evidence on the above relationship in Vietnam, as well as clarifying the contribution level of human capital quality and innovation in technology, industrial growth, and energy consumption to the extent of greenhouse gas emissions in Vietnam in the long and short term. The study expects improvements in the quality of human capital and technological innovation to reduce greenhouse gas emissions, while energy consumption and industrial growth are expected to increase emissions of greenhouse gases in Vietnam.

ARDL model is employed for empirical estimates based on Vietnamese data from 1986 to 2019. The use of greenhouse gas emission index, instead of the commonly used CO2 emission index, is based on the severe impact of greenhouse gases on the environment and is expected to reflect the impact of industrial growth more comprehensively, economics, energy consumption, as well as the role of human capital and technological innovation on the environment. Numerous studies have addressed the connections between industrial growth factors, economic growth, and energy consumption in relation to greenhouse gas emissions. Similarly, there is existing research on the correlation between human capital, technology, and the impact of technology on greenhouse gas emissions. However, there is a lack of studies that synthesize the combined impact of these factors on greenhouse gas emissions. Additionally, there is a dearth of research that specifically addresses the influence of these factors on greenhouse gas emissions in Vietnam. Hence, conducting this research is not only beneficial but also imperative. This study is structured as follows: The subsequent part synthesizes the theoretical basis which is followed by research method described in Part 3, and Part 4 discusses the estimated results. Based on the experimental results, the final part provides conclusions and some recommendations.

2. Literature Review

The intricate link between economic growth and environment has been explained through various theories and empirical studies, among which the Environmental Kuznets Curve (EKC) stands out. The EKC theory posits that emissions increase with economic growth in the early stages of development, followed by a decline in environmental degradation as the economy reaches an advanced level and implements environmentally friendly technology. This is supported by studies conducted by Grossman & Krueger (1995), Panayotou (1993), Beckerman (1992), and Kaika & Zervas (2013). Moreover, when per capita income stabilizes, people demand a better living environment, which contributes to human capital development and enhances understanding of environmental pollution, as highlighted by Barić et al. (2013) and Liu et al. (2022). The EKC theory has been instrumental in guiding numerous empirical studies that explore the determinants of environmental pollution levels (Kaika & Zervas, 2013). In addition to the EKC theory, the STIRPAT model (Stochastic Impacts by Regression on Population, Affluence, and Technology) has also been a significant theoretical underpinning of empirical research on this subject. STIRPAT model was built by Dietz & Rosa (1994), where the dependent variable is explicated by factors such as population, prosperity, and technology. Over time, the STIRPAT model has evolved through modifications in the measurement methodologies of its components. Consequently, there have been studies that have expanded upon the EKC theory and numerous others that have corroborated the Environmental Kuznets Curve hypothesis. However, the conclusions drawn have been disparate. The primary reason for these divergent conclusions about the variables impacting environmental pollution emissions is the varying degrees of economic development in each case study (Zhang & Zhou, 2016).

Research documents on greenhouse gas emissions have significantly expanded in recent decades. Studies have explored the factors affecting greenhouse gas emissions from various perspectives. In these documents, greenhouse gas emissions are explored in relation to human capital, technological innovation, industrial growth, economic growth, energy consumption. Therefore, the overview of research documents is presented according to the following contents:

Industrial growth and greenhouse gas emissions

Industry activities play an important role in the economic development of countries. This is the reason why industrial growth was chosen as the target area to promote economic growth. The world's industry mainly uses fossil fuels for production, so it produces greenhouse gases that damage the environment. Numerous studies have delved into the link between growth in industry sector and CO2 discharges, which represent the largest proportion of greenhouse gases. In Taiwan, for instance, industrial production is closely linked to carbon dioxide emissions (Chang & Lin, 1999), while in Shanghai, industrial production has emerged as the primary driver of rising CO2 emissions between 1996 and 2007 (Zhao et al., 2010). Similarly, the growth and development of the heavy industry sector in China have had a notable positive impact on carbon dioxide emissions. Empirical evidence demonstrates that a 1% growth in heavy industry output leads to a rise in carbon dioxide releases of 0.278% in the long run and 0.147% in the short run (Zhongping et al., 2011). Moreover, between 1993 and 2013, the investment scale of China's industrial sector emerged as the most significant factor contributing to the rise in CO2 emissions (Zhao & Zhang, 2016). In this regard, the growth of the industrial sector has been observed to have a positive impact on CO2 emissions in various studies, including Rahman & Kashem (2017), Abokyi et al. (2019), and Ali et al. (2021). These research results addressed the positive association between the growth in industry and carbon dioxide emissions, given that the increase in added value in the industrial sector translates to more production activities and energy consumption, consequently leading to higher discharges.

Economic growth, energy consumption, and greenhouse gas emissions

Currently, there are still several studies evaluating the bidirectional or unidirectional relationship between economic growth, energy consumption and CO2 emissions such as Yusuf et al. (2020), Le et al. (2020), Khan et al. (2020), Awodumi and Adewuyi (2020), Wen et al. (2021), Radmehr et al. (2021), Mohsin et al. (2021), Espoir et al. (2022). Sufyanullah et al. (2022), Lin et al. (2023), González-Álvarez and Montañés (2023), Liu et al. (2023), Minh et al. (2023), Xie et al. (2023), Raihan (2023), Idroes et al. (2023), Iqbal et al. (2023), Mitić et al. (2023), AlNemer et al. (2023), Sadiq et al. (2023), Eweade et al. (2024), Azzeddine et al. (2024). The development of industrialization and global population growth are the main factors causing climate change (Li et al., 2023). To carry out industrialization and economic growth, a large amount of input must be consumed to serve activities that create wealth for society. Among the inputs used, Industrial energy consumption accounts for 51% of global energy use (IPCC, 2007). In a study predicting CO2 emissions of the world's largest CO2 emitters, the United States, China, and India, Ahmed et al (2023) drew the conclusion that energy consumption is a source of important for greenhouse gas emissions, especially non-renewable energy, the more natural resouces used, the more greenhouse gas emissions are created. Carbon emissions from fossil fuel combustion are the main cause of greenhouse gas intensity (IPCC, 2007). Although fossil fuel consumption is a major contributor to greenhouse gas emissions leading to increased global temperatures (Wang and Azam, 2024), current studies demonstrate that there may or may not exist a relationship between energy consumption and economic growth (Dissanayake et al., 2023; Shahbaz et al., 2020). In developed countries, energy consumption and economic growth have positive impacts on CO2 emissions in both the short and long term, which is true for developing countries in the long term (Li et al. events, 2023). Similar to some studies, Bekun et al. (2019), Ahmed & Wang (2019), Raihan & Tuspekova (2022a, 2022b) also found similar results among these three variables. In the long run, renewable energy consumption has a significant and positive impact on economic output, while in some other countries, renewable energy consumption has a significant and negative impact on growth. economics (Shahbaz et al., 2020). Although there is a positive relationship between CO2 emissions and national prosperity, many countries have maintained economic growth while gradually reducing CO2 emissions (Androniceanu and Georgescu, 2023). Research by Halkos & Gkampoura (2021) across 119 countries has proven this. The relationship between energy consumption, CO2 emissions and economic growth in the studied countries with different income levels shows that the environmental Kuznets curve (EKC) theory is valid for countries with high-income and upper-middle-income, but not for lower-middle-income and low-income countries. Or to put it another way, in high-income and upper-middle income countries, economic growth initially requires a lot of energy consumption, leading to increased CO2 emissions, but then when development reaches a certain level, these countries care about environmental quality. This is not true in poorer countries, because growth is not enough to motivate them to improve environmental quality. Facing the great challenge of economic growth, energy consumption increases greenhouse gas emissions, all researches's implications emphasize the conversion of renewable energy consumption. Much evidence in countries with a strong shift in energy consumption have proven the above suggestions to be correct. The solutions mainly emphasize the government's role in educating people in environmental protection activities and transition to green and renewable energy consumption to significantly reduce CO2 emissions.

Human capital, technological innovation, and greenhouse gas emissions

The role of human capital in relation to growth and CO2 emissions, as well as greenhouse gas emissions, has been substantiated in a multitude of studies. Human capital has been found to make a positive contribution towards the achievement of millennium development goals in developing nations (Baldacci et al., 2008). The development of human capital reduces polluting emissions in the region, reducing the ecological footprint of countries (Serkan, 2009; Ahmed et al., 2020; Ahmed & Wang, 2019; Adikari et al., 2023). Improving labor productivity through education will also reduce CO2 (Bhuiyan et al., 2023). In the long run, human capital has a statistically significant negative impact on carbon emissions, greenhouse gas emissions (Zhang et al., 2021; Sharma et al., 2021; Nguyen & Do, 2023) . On the contrary, there are still studies with contradictory results such as human capital having a positive impact on short-term carbon emissions (Zhang et al., 2021); Greenhouse gas emissions have a positive correlation with GDP and higher education reduce emissions (Furkan et al., 2023); Or there is no causal relationship from human capital, per capita energy consumption and real GDP per capita to CO2 emissions (Bashir et al., 2019). Thus, the previous studies show that the results are still inconsistent, however, in general, the development of human capital reduces CO2 and greenhouse gas emissions.

The relationship between CO2 emissions and technological innovation is also highlighted in many studies. Technological innovation is posited to concurrently enhance environmental conditions and assure productivity (Arrow et al., 1995); Economic growth is propelled by technological innovation that diminishes CO2 emissions (Antweiler et al., 2001; Hasanbeigi et al., 2012; Santra, 2017; Abid et al., 2022). Enabling the transition from the use of fossil fuels to other sustainable energy sources requires new technologies (Nordhaus, 2007; Foxon, 2011), patents, and technological innovations that can reduce energy use further and leads to reductions in CO2 emissions (Voigt et al., 2014; Fernández et al., 2018; Van & Sadradin, 2021; Apostu et al., 2023; Adebayo et al., 2023; Wenlong et al., 2023; Fang, 2023). Higher economic growth will lead to more investment in more advanced technologies, and economic growth is also the main culprit in increasing emissions (Chen & Lei , 2018). On the contrary, in some other studies, the relationship between green technology and CO2 emissions follows a different pattern. Low levels of technological innovation will still increase carbon emissions, but when technological innovation reaches a certain level, carbon emissions will gradually decrease (Chen et al., 2023). Regarding the impact of technological innovation and emissions, research conclusions are still inconsistent, however, in general, technological innovation reduces CO2 emissions and greenhouse gas emissions to the environment.

Upon conducting a comprehensive review of existing literature, it has been discerned by the authors that there exists a multitude of studies investigating the influence of factors such as industrial growth, the growth of economic, energy combustion, human capital and technological innovation on greenhouse gas emissions across various nations. However, the findings from these studies present an inconsistency in terms of the contributions of these factors. The heterogeneity in these results could potentially be attributed to the diverse geographical locations of these studies, the temporal periods they encompass, the distinct data sources utilized, and the varied quantitative methodologies employed. Despite the continual updates and incorporation of novel influential factors in the research literature pertaining to greenhouse gas emissions, there is a conspicuous absence of studies that evaluate the concurrent impact of industrial growth, economic growth, energy consumption, human capital, and technological innovation on greenhouse gas emissions in Vietnam for the period 1986-2030. In the interim, the Vietnamese Government has ratified the National Green Growth Strategy for the period 2021-2030, thereby emphasizing the significance of promoting adjustments in energy structure, development of human capital, and national innovation. Consequently, there is an imperative need for more in-depth research on this subject to facilitate sustainable development in Vietnam. This study, therefore, aspires to contribute additional empirical evidence concerning these relationships and simultaneously provide a foundation for the formulation of judicious policies aimed at fostering economic growth, industrial development, energy consumption, as well as human capital development and technological innovation in Vietnam in the forthcoming years.

3. Methodology

The Autoregressive Distributed Lag (ARDL) methodology was employed, scrutinizing time-series data spanning from 1986 to 2019 pertaining to Vietnam. The variables incorporated in the model, along with their respective data collection sources, are delineated in Table 1. Prior to conducting the analysis, all variables are subjected to a natural logarithmic transformation. Previous research models have analyzed these variables for their impact on CO2 emissions and greenhouse gases. For instance, industrial growth has been proved to have a concomitant effect on CO2 releases (Ali et al., 2021). A bidirectional causal relationship has been identified between energy consumption, GDP, and greenhouse gas emissions (Lu, 2017). Furthermore, population growth has been observed to exert a positive influence on CO2 emissions (Hamilton & Turton, 2002; Lawal & Abubakar, 2019). The measurement of Human Capital (HC) was taken from the Penn World Table version 10.0 (Feenstra et al., 2015) database. This indicator has been previously utilized by Ahmed & Wang (2019) to measure human capital and assess its impact on the ecological footprint in India. To measure technological innovation, the study employs patent applications, a method used in preceding studies (Voigt et al., 2014; Van & Sadradin, 2021). In this study, it is postulated that human capital and technological innovation will contribute to a decrease in greenhouse gas emissions in Vietnam.

The ARDL methodology, built by Pesaran et al. (2001), is employed due to its several advantages: (1) flexibility in cointegration testing (Pesaran et al., 2001); (2) effective applicability to small sample sizes (Odhiambo, 2009); and (3) the provision of unbiased coefficients in the long-term model when applying the ARDL model (Harris & Sollis, 2003).

Based on theory and related studies, the authors construct the following research model:

$$\begin{aligned}\Delta LnGGE_t = \beta_0 &+ \sum_{i=1}^{q} \beta_{1i}\Delta LnGGE_{t-i} + \sum_{i=0}^{q} \beta_{2i}\,\Delta LnGDP_{t-i} + \sum_{i=0}^{q} \beta_{3i}\,\Delta LnIVA_{t-i} + \sum_{i=0}^{q} \beta_{4i}\,\Delta LnP_{t-i} \\ &+ \sum_{i=1}^{q} \beta_{5i}\,\Delta LnHC_{t-i} + \sum_{i=0}^{q} \beta_{6i}\,\Delta LnPAT_{t-i} + \sum_{i=0}^{q} \beta_{7i}\,\Delta LnPEC_{t-i} \\ &+ \gamma_1 LnGGE_{t-1} + \gamma_2 LnGDP_{t-1} + \gamma_3 LnIVA_{t-1} + \gamma_4 LnP_{t-1} + \gamma_5 LnHC_{t-1} \\ &+ \gamma_6 LnPAT_{t-1} + \gamma_7 LnPEC_{t-1} + \varepsilon_t\end{aligned}$$

Where: LnGGE, LnGDP, LnIVAC, LnPEC, LnP, LnPAT, LnHC are the natural logarithms of the variables: GGE emissions, GDP, Industry (including construction) value added; Energy consumption per capita; Population growth; Patent applications; Human capital.

Δ is the first difference of the variables; β are the parameters; εt is the error term.

Table 1. Research data

Variable names	Variable Definitions	Data source
GGE	Greenhouse gas emissions (tons of carbon dioxide)	https://ourworldindata.org (2024)
PEC	Energy consumption per capita (KWh)	
HC	Human capital index, based on years of schooling and returns to education	www.ggdc.net/pwt (2024)

GDP	A representative factor to measure the growth rate of Vietnam's economy, calculated based on real GDP at fixed prices in 2015 (%)	https://data.worldbank.org (2024)
PAT	Patent applications (nonresidents and residents) (This indicator is calculated per capita)	
IVA	Industry (including construction), value added per capita (constant 2015 US$)	
P	Population growth (%)	

Source: *Authors' compilation*

Unit root tests are first conducted to ascertain the stationarity or non-stationarity of the data. The Augmented Dickey-Fuller (ADF) test and the Phillips-Perron (PP) test are the two commonly used unit root tests. Subsequently, cointegration tests are performed to investigate the long-term association between the variables in the model. Hypothesis testing is conducted using the F-test statistic, which compares the upper and lower critical values. Lastly, the error correction model is estimated to examine the short-term association between the variables established earlier.

Optimal lag selection. The optimal lag can be determined by several methods such as AIC, SBC, SIC. The p and q values are selected to minimize the AIC, SBC, and SIC. However, the lag can also be determined automatically in the Eview software.

Bound test. Although economic time series tend to have a deterministic or stochastic trend, there are a group of variables that can fluctuate together. Cointegration analysis allows discovering long-run relationships between variables. There is an expectation on variables to have a long-term relationship with each other because cointegration represents a long-term and stable relationship among variables. Therefore, the variables in the model will form a single cointegrating vector. Consequently, it is necessary to test for cointegration. In the ARDL model, to check whether a long-term relationship exists or not, the Bound test is performed. This method was developed by Pesaran and Shin (1999), Pesaran et al. (2001).

The F statistic was calculated to compare with the critical values of Pesaran et al. (2001). If:

F > Upper Bound : hypothesis that no cointegration relationship exists is not accepted.

F < Lower Bound : accept hypothesis that no cointegration relationship exists .

Upper bound > F > lower bound: there is not enough evidence to conclude about the long-term relationship. In this case, to overcome this problem, the error correction model (ECM) is applied to evaluate the cointegration of variables. With a simple linear equation:

yt = β0 + β1xt + εt

ECM is defined as the residual of the above equation.

The error correction model considering the short-term impact of variables on greenhouse gas emissions is as follows:

$$\Delta LnGGE_t = \beta_0 + \sum_{i=1}^{p} \beta_{1i}\Delta LnGGE_{t-i} + \sum_{i=0}^{q} \beta_{2i}\,\Delta LnGDP_{t-i} + \sum_{i=0}^{q} \beta_{3i}\,\Delta LnIVA_{t-i} + \sum_{i=0}^{q} \beta_{4i}\,\Delta LnP_{t-i} + \sum_{i=0}^{q} \beta_{5i}\,\Delta LnHC_{t-i} + \sum_{i=0}^{q} \beta_{6i}\,\Delta LnPAT_{t-i} + \sum_{i=0}^{q} \beta_{7i}\,\Delta LnPEC_{t-i} + \mu ECT_{t-1} + u_t$$

In the above equation, μ is the coefficient of the error correction term (ECT). This coefficient represents the degree of return to the equilibrium state of the economy under the impact of short-term shocks.

Diagnostic test. Lagrange multiplier test (LM) to test the serial correlation between the residuals at the first – order lags (H_0: There is no serial correlation of the residuals to the first – order lag).

Breusch-Pagan-Godfrey test to test heteroskedasticity (H_0: Heteroscedasticity).
Jarque Bera test to test normal distribution in residuals (H_0: residuals are normally distributed).
Robustness checks. Lu and White (2014), Sowah and Kirikkaleli (2022) suggested FMOLS, DOLS, CCR, FGLS, FOGLeSs estimators to.check robustness regressions. According to Sowah and Kirikkaleli (2022), these approaches are appropriate for addressing issues in cointegrating regressions. Thus the study chooses DOLS, FGLS and FMOLS tools to test the robustness of the model.

4. Results

Table 2 describes the criteria of Vietnam in the period from 1986 to 2019.

Table 2. Descriptive statistics

	LnGGE	LnGDP	LnPEC	LnIVA	LnHC	LnPAT	LnP
Mean	19.33	1.86	8.10	6.10	0.75	-11.43	0.27
Median	19.43	1.90	8.12	6.22	0.73	-11.01	0.07
Maximum	20.18	2.25	9.44	7.07	1.05	-9.41	0.85
Minimum	18.50	1.02	6.99	5.11	0.52	-17.23	-0.09
Std. Dev.	0.49	0.25	0.79	0.63	0.17	1.83	0.33
Skewness	-0.21	-1.24	0.03	-0.28	0.26	-1.34	0.65
Kurtosis	2.00	5.43	1.70	1.72	1.67	4.29	1.74
Jarque-Bera	1.67	17.22	2.39	2.74	2.90	12.66	4.67
Observations	34	34	34	34	34	34	34

Source: *Author's calculations*

Vietnam experienced a remarkable economic growth rate from 1986 to 2019, placing it among the countries with high economic growth rates in the world. The country's human capital index has also exhibited a positive trend, registering an above-average score of 2. However, the rate of patent applications per capita in Vietnam has remained low. Additionally, the country's energy consumption levels as well as greenhouse gas emissions, when compared to GDP, are higher than those of many other countries. In 2016, Vietnam's total net greenhouse gas emissions stood at 316,734.96 thousand tons of CO2 equivalent. Notably, greenhouse gas emissions from the energy sector were the highest, accounting for 65% of total emissions. The industrial processes and product use sector followed closely behind, accounting for 14.6% of emissions. Despite efforts to curb emissions, the energy sector is still projected to be the largest source of greenhouse gas emissions in Vietnam by 2030.

Table 3: Greenhouse gas emissions of Vietnam in the years 1994, 2000 and 2010 and estimates for the year 2030

(Unit: Million Tonnes of carbon dioxide equivalent)

Sectors	**1994**	**2000**	**2010**	**2014**	**2016**	**2030 (estimate)**
Energy	25,6	52,8	151. 88	175.54	205,83	648,5
The industrial process and product usage	3,8	10,0	25,84	38,73	46,09	-

Source: *Ministry of Natural Resources & Environment (2014, 2020)*

The J-B test results also demonstrate the normal distribution of all variables. The mean and median values of most variables are consistent (Table 1). GGE, PEC, IVA, HC, and PAT all show an increasing trend over time, while variable P shows a decreasing trend during the period 1986-2019 (Figure 1).

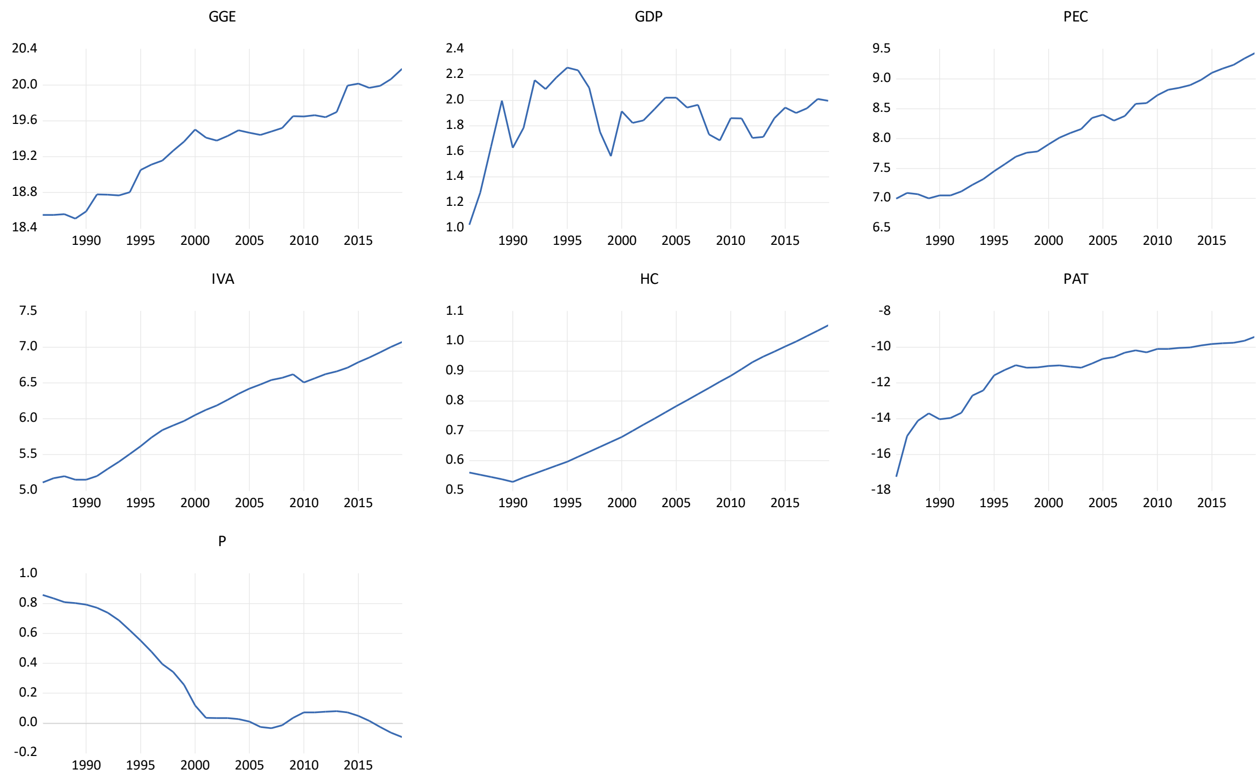

Fig. 1: The variation of variables

Table 4 shows the results of the unit root test. It is observed that some variables require first differencing to achieve stationarity, while others are stationary at the 1% and 5% significance levels. Thus, the data series satisfies the necessary conditions for proceeding with the ARDL model to analyze the impact of industrial growth, economic growth, energy consumption, human capital, and technological innovation on greenhouse gas emissions in Vietnam from 1986 to 2019.

Table 4. Unit Root Test

Variables	**ADF Test**		**PP Test**	
	Level Intercept	**1st Difference Intercept**	**Level Intercept**	**1st Difference Intercept**
LnGGE	-3.02	-5.45***	-2.45	-5.09***
LnIVA	-1.09	-3.57**	-1.61	-3.57**
LnGDP	-3.89**	-	-3.88**	-
LnP	-3.84**	-	-1.17	-2.02
LnHC	-5.16***	-	-8.95***	-
LnPEC	-3.70**	-	-3.03	-4.89***
LnPAT	-1.66	-7.37***	-4.87***	-

Source: Authors' calculations

*Note: ***, **, * Corresponding to statistical significance levels of 1%, 5%, 10%*

Table 5 and Figure 2 show that the ARDL (1, 2, 1, 0, 3, 3, 3) model has the smallest AIC value, so it is the model used for analysis.

Table 5. Optimal lag selection

Lag	LogL	LR	FPE	AIC	SC	HQ
0	164.61	NA	9.04e-14	-10.16	-9.84	-10.06
1	417.63	375.43	1.89e-19	-23.33	-20.74	-22.48
2	501.50	86.57	3.40e-20	-25.58	-20.72	-23.99
3	628.57	73.78*	1.42e-21*	-30.61*	-23.49*	-28.29*

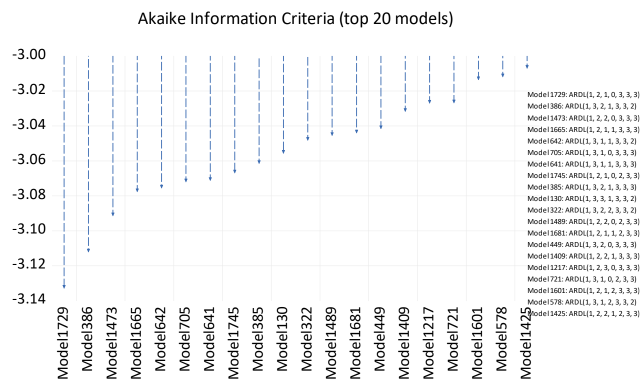

Fig. 2: AIC standard for the 20 best ARDL models

The findings from the ARDL bounds testing are presented in Table 6. The empirical evidence from the test suggests the existence of a long-term equilibrium relationship among the variables incorporated in the model. This is substantiated by the F-statistic value surpassing the critical upper bound value at a 1% level of significance. Consequently, it can be inferred that a long-term association is indeed present among the variables under consideration.

Table 6. ARDL Bound Testing Results

F-Bounds Test				
Test Statistic	Value	Signif.	I (0)	I (1)
F-statistic	7.46	10%	1.99	2.94
k	6	5%	2.27	3.28
		2.5%	2.55	3.61
		1%	2.88	3.99

Source: *Authors' Calculations*

Table 7. Long-term coefficient estimation results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LnGDP	-0.18	0.12	-1.39	0.1911
LnPEC	0.52	0.24	2.17	0.0520
LnIVA	1.29	0.40	3.17	0.0089
LnHC	-3.31	1.11	-2.98	0.0124
LnPAT	0.16	0.06	2.77	0.0179
LnP	1.27	0.36	3.50	0.0049
C	11.77	2.50	4.70	0.0006

Source: *Authors' Calculations*

The findings in table 7 indicate that the variable LnGDP is not statistically significant within the confines of the model, meaning that there is no evidence to conclude the existence of relationship between economic output and carbon emissions in Vietnam. This result aligns with the study conducted by Adikari et al. (2023) on the Sri Lankan economy during the period 1978-2019. During the initial phase of the reform period, Vietnam's economic growth was predominantly driven by the agricultural sector, followed by the service sector, and subsequently the industrial sector. At that time, the agricultural practices in Vietnam employed rudimentary techniques, resulting in minimal CO2 emissions. Subsequently, the nation's economic focus gradually transitioned towards industrial and service activities. By 2019, the service, industrial, and agricultural sectors contributed approximately 42.47%, 36.8%, and 11.78% to the economy, respectively (General Statistics Office, 2019). Notably, it was the service sector, as opposed to the industrial sector, that played a vital role in propelling economic growth during this period. The service sector is characterized by low energy consumption, thereby contributing to Vietnam's overall lower per capita energy consumption when compared to the global average. As a result, there appears to be no definitive correlation between CO2 emissions and the economic output in Vietnam, demonstrating the unique economic reality of the country. The variables LnPEC, LnIVA, LnHC, LnPat, and LnP demonstrate statistical significance with greenhouse gas emissions in Vietnam at varying levels of significance. Specifically, at the 10% level of significance, a 1% rise in energy combustion increases greenhouse gas emissions by 0.525%. This result is congruent with the findings of Hamit-Haggar (2012) and Lu (2017). At the 1% level of significance, the growth of the industrial sector also contributes to an increase in greenhouse gas emissions. This finding corroborates the research of Zhongping et al. (2011) and Ali et al. (2021). Furthermore, population growth also positively correlates with an increase in greenhouse gas emissions, which is consistent with the research conducted by Lawal & Abubakar (2019). However, at the 5% level of significance, the impact of LnPAT (representing technological innovation) on greenhouse gas emissions is positive. This suggests that technological innovation does not contribute to the reduction of greenhouse gas emissions in Vietnam. This finding is in line with the research of Peizhen et al. (2014) and Van & Sadradin (2021). The rationale behind this can be attributed to the use of a proxy variable, which, in this case, is the annual number of patents. Selecting a variable that accurately represents technological development in Vietnam poses significant challenges, as there is no official data that quantifies changes in the country's technological landscape. While the number of patents in Vietnam has exhibited an upward trend over the years, the culture of patent registration in Vietnam remains underdeveloped. Many inventors refrain from registering their patents, and the bulk of patent registrations are attributed to foreign entities. Consequently, the tangible impact of patents on real-life products has not been conclusively demonstrated through the number of patent registrations. As a result, the conventional theoretical framework may not accurately capture the influence of the patent variable on CO2 emissions. Human capital (HC) has been empirically found to play a pivotal role in reducing carbon emissions and greenhouse gas emissions, thereby ensuring environmental quality. At the 5% level of significance, a 1% increase in human capital results in a 3.314% reduction in greenhouse gas emissions. This suggests that human capital positively contributes to the reduction of greenhouse gas emissions in Vietnam. This finding is consistent with several previous studies (e.g., Serkan (2009), Ahmed et al. (2020), Sharma et al. (2021), Ahmed & Wang (2019), and Adikari et al. (2023)).

Table 8. Short-term coefficient estimation results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(LnGDP)	0.31	0.05	5.90	0.0001
D(LnGDP(-1))	0.24	0.06	3.76	0.0031
D(LnPEC)	0.15	0.12	1.21	0.2489
D(LnHC)	-8.03	1.81	-4.42	0.0010
D(LnHC(-1))	-11.70	2.25	-5.19	0.0003
D(LnHC(-2))	4.58	1.56	2.93	0.0136

D(LnPAT)	0.06	0.03	1.98	0.0727
D(LnPAT(-1))	-0.24	0.03	-6.64	0.0000
D(LnPAT(-2))	-0.16	0.02	-5.59	0.0002
D(LnP)	1.09	0.35	3.08	0.0103
D(LnP(-1))	-0.56	0.44	-1.25	0.2346
D(LnP(-2))	-0.92	0.30	-2.97	0.0126
CointEq(-1)*	-1.09	0.11	-9.88	0.0000

The results of the error correction model derived from the ARDL model have been estimated to investigate the existence of the cointegration relationship between industrial growth, economic growth, energy consumption, human capital, technological innovation, and greenhouse gas emissions. The estimated results have been proved to be statistically significant at the 1% level (Table 8), which eliminates the suspicion of the aforementioned relationship. This finding is of utmost importance as it demonstrates the reliability of the policy recommendations proposed in this study.

Furthermore, the estimated coefficients are presented in Table 8. In the short term, the relationship between the variables and greenhouse gas emissions has been found to be significant at the 1% and 5% levels, except for the variables of industrial growth and energy consumption. The positive impacts of economic growth and population growth on greenhouse gas emissions have been observed, whereas, at the first difference level, a 1% increase in technological innovation has been found to contribute to a reduction of 0.246% in greenhouse gas emissions. Similarly, the role of human capital has been found to be important in reducing greenhouse gas emissions in the short term as well, with a 1% increase in human capital resulting in an 8.033% reduction in greenhouse gas emissions. These findings are consistent with expectations and the results of previous studies.

To assess the stability and suitability of the estimated ARDL model, various tests including the autocorrelation phenomenon test, the variance of the error does not change, and the residual test have been conducted, and the results are presented in Table 9. All tests have failed to reject the null hypothesis, indicating that the estimated model is free from autocorrelation phenomenon, the variance of the error changes, and the model has residuals that are normally distributed. This ensures the reliability and validity of the estimated ARDL model.

Table 9: Summary of Model Tests

Model Tests	**Hypothesis**	**F-statistic**	**Probability**	**Decision**
Ramsey Test	H_0: Normally distributed residuals	0.64	0.4413	Do not reject H_0
Serial Correlation LM Test	H_0: No autocorrelation	2.18	0.1688	Do not reject H_0
Breusch – pagan -Godfrey Test	H_0: error variance remains unchanged	1.97	0.1239	Do not reject H_0

The stability analysis of the CUSUM and CUSUMQ regression coefficients has been illustrated in Figure 3. Upon careful examination, it can be observed that both CUSUM and CUSUMQ lines remain within the confidence band at the 5% significance level, which suggests that the residuals of the model are stable. Consequently, it can be ascertained that the model is appropriate for analytical purposes.

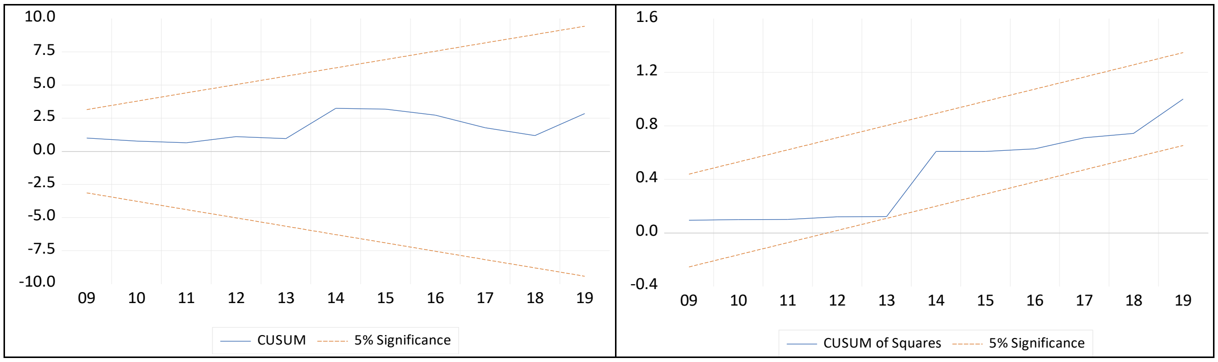

Fig. 3: The stability analysis of the CUSUM and CUSUMQ

Table 10: Robustness check

Regressors	**DOLS**	**FMOLS**	**CCR**
LnGDP	-0.818439	-0.002913	-0.004018
LnPEC	0.237029	0.775771	0.769205
LnIVA	2.378800	0.191837	0.140036
LnHC	-4.504085	-1.430882	-1.313070
LnPAT	0.134151	0.017352	0.026145
LnP	1.907097	0.082644	0.059344
Lead	1		
Lag	1		

The estimated coefficients from the Dynamic Ordinary Least Squares (DOLS), Fully Modified Ordinary Least Squares (FMOLS), and Canonical Cointegrating Regression (CCR) models consistently demonstrate the impact directions across all variables. Notably, Gross Domestic Product (GDP) and Human Capital (HC) exhibit inverse effects on the dependent variable, while Private Expenditure on Consumption (PEC), Investment Value Added (IVA), Public Administration and Taxes (PAT), and Population (P) show effects in the same direction as the dependent variable. These results are consistent with the findings in the research regression model, indicating robustness and reliability of the regression results.

5. Conclusion and Recommendations

In conclusion, this study contributes to the literature by providing empirical evidence on the determinants of greenhouse gas emissions in Vietnam, a rapidly industrializing economy. The findings highlight the positive long-run impacts of industrial growth, population growth, energy consumption, and technological innovation on emissions. Notably, human capital development emerges as a key factor in reducing emissions, both in the short and long run. These results have important policy implications for Vietnam's efforts to balance economic development and environmental sustainability.

Based on the findings, the study recommends a multi-pronged policy approach. First, investing in education and human capital development is crucial for promoting environmental awareness and facilitating the adoption of cleaner technologies and practices. Second, industrial policies should prioritize the transition towards green and high-value-added sectors with lower emissions intensities. Third, efforts should be made to diversify the energy mix by increasing the share of renewable sources and promoting energy efficiency measures. Finally, technological innovation policies should be aligned with environmental objectives to ensure that new technologies contribute to emissions reduction rather than exacerbating the problem.

While this study provides valuable insights, it is important to acknowledge its limitations. First, the analysis is based on aggregate national-level data, which may obscure heterogeneities and dynamics at more granular levels (e.g., across regions, industries, or firms). Future research could explore these disaggregated dimensions to derive more nuanced policy implications. Additionally, the study does not account for potential non-linearities or threshold effects in the relationships between the variables, which could be explored using more advanced econometric techniques.

References

Abbasi, F., & Riaz, K. (2016). CO2 emissions and financial development in an emerging economy: an augmented VAR approach. *Energy Policy*, 90, 102-114.

Abid, A., Mehmood, U., Salman, T., & Haq, Z. U. (2022). The effect of technological innovation, FDI, and financial development on CO2 emission: Evidence from the G8 countries. *Environmental Science and Pollution Research*, 29 (8), 11654-11662.

Abokyi, E., Appiah-Konadu, P., Abokyi, F., & Oteng-Abayie, E.F. (2019). Industrial growth and emissions of CO2 in Ghana: The role of financial development and fossil fuel consumption. *Energy Reports*, 5, 1339–1353.

Adebayo, T. S., Ullah, S., Kartal, M. T., Ali, K., Pata, U. K., & Ağa, M. (2023). Endorsing Sustainable Development in BRICS: The Role of Technological Innovation, Renewable Energy Consumption, and Natural Resources in Limiting Carbon Emission. *Science of The Total Environment*, 859, 160181.

Adikari, AM. P., Liu, H., Dissanayake, DMSLB., & Ranagalage, M. (2023). Human Capital and Carbon Emissions: The Way forward Reducing Environmental Degradation. *Sustainability*, 15(4), 2926.

Ahmed Z, Zafar MW, Ali S., & Danish. (2020). Linking urbanization, human capital, and the ecological footprint in G7 countries: An empirical analysis. *Sustainable Cities Society*, 55, 102064.

Ahmed, M., Shuai, C., & Ahmed, M. (2023). Analysis of energy consumption and greenhouse gas emissions trend in China, India, the USA, and Russia. *International Journal of Environmental Science and Technology*, 20(3), 2683-2698.

Ahmed, Z., & Wang, Z. (2019). Investigating the Impact of Human Capital on the Ecological Footprint in India: An Empirical Analysis. *Environmental Science and Pollution Research*, 26, 26782–26796.

Ali, K., Bakhsh, S., Ullah, S., Ullah, A., & Ullah, S. (2021). Industrial Growth and CO2 Emissions in Vietnam: The Key Role of Financial Development and Fossil Fuel Consumption. *Environmental Science and Pollution Research*, 28, 7515-7527.

AlNemer, H. A., Hkiri, B., & Tissaoui, K. (2023). Dynamic impact of renewable and non-renewable energy consumption on CO2 emission and economic growth in Saudi Arabia: Fresh evidence from wavelet coherence analysis. *Renewable Energy*, 209, 340-356.

Androniceanu, A., & Georgescu, I. (2023). The impact of CO2 emissions and energy consumption on economic growth: a panel data analysis. *Energies*, 16(3), 1342.

Antweiler, W., Copeland, B.R., & Taylor, M.S. (2001). Is free trade good for the environment?. *American Economic Review*, 91(4), 877-908.

Apostu, S. A., Nichita, E. M., Manea, C. L., Irimescu, A. M., & Vulpoi, M. (2023). Exploring the Influence of Innovation and Technology on Climate Change. *Energies*, 16(17), 1-13.

Arrow, K., Bolin, B., Costanza, R., Dasgupta, P., Folke, C., Holling, C.S., Jansson, B.O., Levin, S., Mäler, K.G., Perrings, C., & Pimentel, D. (1995). Economic growth, carrying capacity, and the environment. *Ecological Economics*, 15 (2), 91 - 95.

Audinet, P., Singh, B., Kexel, D.T. Suphachalasai, S., Makumbe, P., & Mayer, K. (2016). Exploring a Low-Carbon Development Path for Vietnam. The World Bank.

Awodumi, O. B., & Adewuyi, A. O. (2020). The role of non-renewable energy consumption in economic growth and carbon emission: Evidence from oil producing economies in Africa. Energy Strategy Reviews, 27, 100434.

Azzeddine, B. B., Hossaini, F., & Savard, L. (2024). Greenhouse gas emissions and economic growth in Morocco: A decoupling analysis. *Journal of Cleaner Production*, 450, 141857.

Baldacci, E., Clements, B., Gupta, S., & Cui, Q. (2008). Social spending, human capital, and growth in developing countries. *World Development*, 36(8), 1317-1341.

Barić, D., Zovak, G., and Periša, M. (2013). Effects of eco-drive education on the reduction of fuel consumption and CO2 emissions. *Promet-Traffic &Transportation*, 25(3), 265–272.

Bashir, A., Thamrin, K. M. H., Farhan, M., Mukhlis, M., & Atiyatna, D. P. (2019). The Causality between Human Capital, Energy Consumption, CO2 Emissions, and Economic Growth: Empirical Evidence from Indonesia. *International Journal of Energy Economics and Policy*, 9(2), 98–104.

Beckerman, W. J. W. d. (1992). Economic growth and the environment: Whose growth? Whose environment?, 20(4), 481-496.

Bekun, F.V. et al. (2019). Toward a Sustainable Environment: Nexus between CO2 Emissions, Resource Rent, Renewable and Nonrenewable Energy in 16-EU Countries. *Science of the Total Environment*, 657, 1023-1029.

Bhuiyan, M. A., Kahouli, B., Hamaguchi, Y., & Zhang, Q. (2023). RETRACTED ARTICLE: The role of green energy deployment and economic growth in carbon dioxide emissions: evidence from the Chinese economy. *Environmental Science and Pollution Research*, 30(5), 13162-13173.

Chang, T. C., & Lin, S. J., (1999). Grey relation analysis of carbon dioxide emissions from industrial production and energy uses in Taiwan. *Journal of Environmental Management*, 56(4), 247-257.

Chen, H., Yi, J., Chen, A., Peng, D., & Yang, J. (2023). Green technology innovation and CO2 emission in China: Evidence from a spatial-temporal analysis and a nonlinear spatial durbin model. *Energy Policy*, 172, 113338.

Chen, W., & Lei, Y. (2018). The impacts of renewable energy and technological innovation on environment-energy-growth nexus: New evidence from a panel quantile regression. Environmental Science, Economics: *Renewable Energy*, 123, 1–14.

Dietz, T., & Rosa, E. (1994). Rethinking the environmental impacts of population, affluence and technology. *Human Ecology Review*, 1(2), 277-300.

Dissanayake, H., Perera, N., Abeykoon, S., Samson, D., Jayathilaka, R., Jayasinghe, M., & Yapa, S. (2023). Nexus between carbon emissions, energy consumption, and economic growth: Evidence from global economies. Plos one, 18(6), e0287579

Edoja, P. E., Aye, G. C., & Abu, O. (2016). Dynamic relationship among CO2 emission, agricultural productivity and food security in Nigeria. *Cogent Economics & Finance*, 4(1), 1204809.

Espoir, D. K., Mudiangombe, B. M., Bannor, F., Sunge, R., & Tshitaka, J. L. M. (2022). CO2 emissions and economic growth: Assessing the heterogeneous effects across climate regimes in Africa. *Science of the Total Environment*, 804, 150089.

Eweade, B. S., Uzuner, G., Akadiri, A. C., & Lasisi, T. T. (2024). Japan energy mix and economic growth nexus: Focus on natural gas consumption. *Energy & Environment*, 35(2), 692-724.

Fang, Z. (2023). Assessing the impact of renewable energy investment, green technology innovation, and industrialization on sustainable development: A case study of China. *Renewable Energy*, 205, 772-782.

Feenstra, C. R., Inklaar, R., & Timmer, P. M. (2015). The next generation of the Penn World Table. *American Economic Review*, 105(10), 3150–3182.

Fernández, Y. F., López, M. F., & Blanco, B. O. (2018). Innovation for sustainability: The impact of R&D spending on CO emissions. *Journal of Cleaner Production*, 171, 3459-3467.

Foxon, T. J. (2011). A coevolutionary framework for analysing a transition to a sustainable low carbon economy. *Ecological Economics*, 70(12), 22258 – 22267.

Furkan, H. B., Hasan, K. M. R., & Uddin, M. J. (2023). Greenhouse gas emission, GDP, tertiary education, and rule of law: A comparative study between high-income and lower-middle income countries. *Heliyon*, 9(6): e16265.

Grossman, G. M., & Krueger, A. B. (1995). Economic growth and the environment. *The quarterly journal of economics*, 110(2), 353-377.

Halicioglu, F., (2009). An econometric study of CO2 emissions, energy consumption, income and foreign trade in Turkey. *Energy Policy*, 37(3), 1156-1164.

Halkos, G. E., & Gkampoura, E. C. (2021). Examining the Linkages among Carbon Dioxide Emissions, Electricity Production and Economic Growth in Different Income Levels. *Energies*, 14 (6), 1682.

Hamilton, C., & Turton, H. (2002). Determinants of Emissions Growth in OECD countries. *Energy Policy*, 30, 63-71.

Hamit-Haggar, M. (2012). Greenhouse gas emissions, energy consumption and economic growth: A panel cointegration analysis from Canadian industrial sector perspective. *Energy Economics*, 34 (1), 358-364.

Harris, R., & Sollis, R. (2003). Applied time series modelling and forecasting, Wiley.

Hasanbeigi, A., Price, L. & Lin, E. (2012). Emerging energy-efficiency and CO emissionreduction technologies for cement and concrete production: A technical review. *Renewable and Sustainable Energy Reviews*, 16 (8), 6220 – 6238.

Idroes, G. M., Hardi, I., Noviandy, T. R., Sasmita, N. R., Hilal, I. S., Kusumo, F., & Idroes, R. (2023). A deep dive into Indonesia's CO2 emissions: The role of energy consumption, economic growth and natural disasters. *Ekonomikalia Journal of Economics*, 1(2), 69-81.

IPCC. (2007). Summary for policymakers of the synthesis report of the IPCC Fourth Assessment Report. Cambridge, UK: Cambridge University Press.

IPCC. (2014). Climate Change 2014: Synthesis Report. Summary for Policymakers, An Assessment of the Intergovernmental Panel on Climate Change.

Iqbal, A., Tang, X., & Rasool, S. F. (2023). Investigating the nexus between CO2 emissions, renewable energy consumption, FDI, exports and economic growth: evidence from BRICS countries. *Environment, Development and Sustainability*, 25(3), 2234-2263.

Kaika, D., & Zervas, E. J. E. P. (2013). The Environmental Kuznets Curve (EKC) theory—Part A: Concept, causes and the CO2 emissions case. 62, 1392-1402.

Khan, M. K., Khan, M. I., & Rehan, M. (2020). The relationship between energy consumption, economic growth and carbon dioxide emissions in Pakistan. *Financial Innovation*, 6(1), 1.

Lawal, M., & Abubakar, M. (2019). Impact of population growth on Carbon Dioxide (CO2) emission: empirical evidence from Nigeria Ibrahim. Jurnal Perspektif Pembiayaan dan Pembangunan Daerah, 6 (6), 701-708.

Le, T. H., Chang, Y., & Park, D. (2020). Renewable and nonrenewable energy consumption, economic growth, and emissions: International evidence. The Energy Journal, 41(2), 73-92.

Li, J., Irfan, M., Samad, S., Ali, B., Zhang, Y., Badulescu, D., & Badulescu, A. (2023). The relationship between energy consumption, CO2 emissions, economic growth, and health indicators. *International Journal of Environmental Research and Public Health*, 20(3), 2325.

Lin, T. Y., Chiu, Y. H., Lin, Y. N., Chang, T. H., & Lin, P. Y. (2023). Greenhouse gas emission indicators, energy consumption efficiency, and optimal carbon emission allowance allocation of the EU countries in 2030. *Gas Science and Engineering*, 110, 204902.

Liu, H., Wong, W. K., Cong, P. T., Nassani, A. A., Haffar, M., & Abu-Rumman, A. (2023). Linkage among Urbanization, energy Consumption, economic growth and carbon Emissions. Panel data analysis for China using ARDL model. Fuel, 332, 126122.

Liu, N., Hong, C., & Sohail, M. T. (2022). Does financial inclusion and education limit CO2 emissions in China? A new perspective. *Environmental Science and Pollution Research*, 29(13), 18452–18459.

Lu, W. (2017). Greenhouse Gas Emissions, Energy Consumption and Economic Growth: A Panel Cointegration Analysis for 16 Asian Countries. *International Journal of Environmental Research and Public Health*, 14(11), 1-15.

Lu, X., & White, H. (2014). Robustness checks and robustness tests in applied economics. *Journal of econometrics*, 178, 194-206.

Minh, T. B., Ngoc, T. N., & Van, H. B. (2023). Relationship between carbon emissions, economic growth, renewable energy consumption, foreign direct investment, and urban population in Vietnam. Heliyon, 9(6).

Ministry of natural resources and environment. (2014). Báo cáo cập nhật hai năm một lần lần thứ nhất của việt nam cho công ước khung của liên hợp quốc về biến đổi khí hậu. Viet nam publishing house of natural resources environment and cartography. 1247391836_Viet-Nam_BUR1_VN_Final.pdf (dcc.gov.vn)

Ministry of natural resources and environment. (2020), Báo cáo cập nhật hai năm một lần, lần thứ ba, gửi công ước khung của liên hợp quốc về biến đổikhí hậu. Viet nam publishing house of natural resources environment and cartography.

Mitić, P., Fedajev, A., Radulescu, M., & Rehman, A. (2023). The relationship between CO2 emissions, economic growth, available energy, and employment in SEE countries. *Environmental Science and Pollution Research*, 30(6), 16140-16155.

Mohsin, M., Kamran, H. W., Nawaz, M. A., Hussain, M. S., & Dahri, A. S. (2021). Assessing the impact of transition from nonrenewable to renewable energy consumption on economic growth-environmental nexus from developing Asian economies. *Journal of environmental management*, 284, 111999.

Nguyen, H. M & Do, K. L. (2023). Impact of human development on CO2 emissions in Vietnam. Hue University Journal of Science: *Economics and Development*, 132, (5B), 53–66

Nordhaus, W. D. (2007). Areview ofthe Stern review on the economics of climate change. *Journal of Economic Literature*, 45(3), 686 -702

Odhiambo, N. M. (2009). Energy consumption and economic growth nexus in Tanzania: An ARDL bounds testing approach. *Energy policy*, 37(2), 617–622.

Panayotou, T. (1993). Empirical tests and policy analysis of environmental degradation at different stages of economic development.

Peizhen, J., Yabin, Z., & Xing, P. (2014). The double-edged effect of technological progress in carbon dioxide emission reduction—Based on the empirical evidence of 35 industries in China. *Journal Science Research*, 32(05), 706-716.

Pesaran, M.H., Shin, Y., & Smith, R.J. (2001). Bounds testing approaches to the analysis of level relationships. *Journal of Applied Econometrics*, 16(3), 289–326.

Rahman, M, M., & Kashem, M, A. (2017). Carbon emissions, energy consumption and industrial growth in Bangladesh: Empirical evidence from ARDL cointegration and Granger causality analysis. *Energy Policy*, 110(C), 600-608.

Raihan, A. & Tuspekova, A. (2022a). Role of Economic Growth, Renewable Energy, and Technological Innovation to Achieve Environmental Sustainability in Kazakhstan. *Current Research in Environmental Sustainability*, 4, 100165.

Raihan, A. (2023). An econometric evaluation of the effects of economic growth, energy use, and agricultural value added on carbon dioxide emissions in Vietnam. *Asia-Pacific Journal of Regional Science*, 7(3), 665-696.

Raihan, A., & Tuspekova, A. (2022b). The Nexus between Economic Growth, Energy Use, Urbanization, Tourism, and Carbon Dioxide Emissions: New Insights from Singapore, *Sustainability Analytics and Modeling.*

Sadiq, M., Kannaiah, D., Yahya Khan, G., Shabbir, M. S., Bilal, K., & Zamir, A. (2023). Does sustainable environmental agenda matter? The role of globalization toward energy consumption, economic growth, and carbon dioxide emissions in South Asian countries. *Environment, Development and Sustainability*, 25(1), 76-95.

Santra, S. (2017). The efect of technological innovation on production-based energy and CO emission productivity: evidence from BRICS countries. *African Journal of Science, Technology, Innovation and Development*, 9(5), 503 – 512.

Saqib, N. (2018). Greenhouse Gas Emissions, Energy Consumption and Economic Growth: Empirical Evidence from Gulf Cooperation Council Countries. *International Journal of Energy Economics and Policy*, 8(6), 392-400.

Serkan, G. (2009). Economic Growth, Industrial Pollution and Human Development in the Mediterranean Region. *Ecological Economics*, 68 (8-9), 2327–2335.

Shahbaz, M., Raghutla, C., Chittedi, K. R., Jiao, Z., & Vo, X. V. (2020). The effect of renewable energy consumption on economic growth: Evidence from the renewable energy country attractive index. *Energy*, 207, 118162.

Sharma, G.D.; Shah, M.I.; Shahzad, U.; Jain, M.; Chopra, R. Exploring the Nexus between Agriculture and Greenhouse Gas Emissions in BIMSTEC Region: The Role of Renewable Energy and Human Capital as Moderators. *Journal of Environmental Management,* 297, 113316.

Sowah Jr, J. K., & Kirikkaleli, D. (2022). Investigating factors affecting global environmental sustainability: evidence from nonlinear ARDL bounds test. *Environmental Science and Pollution Research*, 29(53), 80502-80519.

Soytas, U., Sari, R., & Ewing, B. T. (2007). Energy consumption, income, and carbon emissions in the United States. *Ecological Economics*, 62(3), 482-489.

Sufyanullah, K., Ahmad, K. A., & Ali, M. A. S. (2022). Does emission of carbon dioxide is impacted by urbanization? An empirical study of urbanization, energy consumption, economic growth and carbon emissions-Using ARDL bound testing approach. *Energy Policy*, 164, 112908.

Van, M. H., & Sadradin, H.F. (2021). The Effect of Technological Innovation On Co2 Emissions in OECD Countries: Using Panel Regression. *International Journal of Contemporary Economics and Administrative Sciences,* XI (2), 438-453.

Voigt, S., De Cian, E., Schymura, M., & Verdolini, E. (2014). Energy intensity developments in 40 major economies: structural change or technology improvement?. *Energy Economics*, 41(C), 47–62.

Wang, J., & Azam, W. (2024). Natural resource scarcity, fossil fuel energy consumption, and total greenhouse gas emissions in top emitting countries. *Geoscience Frontiers*, 15(2), 101757.

Wen, J., Mughal, N., Zhao, J., Shabbir, M. S., Niedbała, G., Jain, V., & Anwar, A. (2021). Does globalization matter for environmental degradation? Nexus among energy consumption, economic growth, and carbon dioxide emission. *Energy policy*, 153, 112230.

Wenlong, Z., Tien, N. H., Sibghatullah, A., Asih, D., Soelton, M., & Ramli, Y. (2023). Impact of energy efficiency, technology innovation, institutional quality, and trade openness on greenhouse gas emissions in ten Asian economies. *Environmental science and pollution research*, 30(15), 43024-43039.

World Bank. (2022). Vietnam Country Climate and Development Report. World Bank.

Xie, L., Mu, X., Lu, K., Hu, D., & Hu, G. (2023). The time-varying relationship between CO2 emissions, heterogeneous energy consumption, and economic growth in China. *Environment, development and sustainability*, 25(8), 7769-7793.

Yusuf, A. M., Abubakar, A. B., & Mamman, S. O. (2020). Relationship between greenhouse gas emission, energy consumption, and economic growth: evidence from some selected oil-producing African countries. *Environmental science and pollution research*, 27(13), 15815-15823.

Zhang, C., & Zhou, X. (2016). Does foreign direct investment lead to lower CO2 emissions? Evidence from a regional analysis in China. *Renewable and Sustainable Energy Reviews*, 58, 943-951.

Zhang, L., Godil, D. I., Bibi, M., Khan, M. K., Sarwat, S., & Anser, M. K. (2021). Caring for the Environment: How Human Capital, Natural Resources, and Economic Growth Interact with Environmental Degradation in Pakistan? A Dynamic ARDL Approach. *Science of the Total Environment*, 774, 145553.

Zhao, M., Tan, L., Zhang, W., Ji, M., Liu, Y., & Yu, L. (2010). Decomposing the influencing factors of industrial carbon emissions in Shanghai using the LMDI method. *Energy*, 35(6), 2505-2510.

Zhongping, W., Changliang, S., Qiang, L., & Gang, W. (2011). Impact of Heavy Industrialization on the Carbon Emissions: An Empirical Study of China. *Energy Procedia*, 5, 2610–2616.