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Relationship between carbon emissions, economic growth, renewable energy consumption, foreign direct investment, and urban population in Vietnam

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ABSTRACT

At the 26th UN Climate Change Conference in late 2021, Vietnam set a target of achieving net-zero carbon (CO_2) emissions by 2050. However, the country's rapid economic growth, urbanization, and industrialization have historically relied on coal-based energy, a source of significant greenhouse gas (GHG) emissions. Although contributing only 0.8% of the world's emissions over the last two decades, Vietnam currently has one of the fastest increasing GHG emissions rates per capita. Over the 2000–2015 period, Vietnam's per capita gross domestic product increased from $390 to $2,000, and CO_2 emissions nearly quadrupled. Hence, this research explores the causal relationships among CO_2 emissions, economic growth, foreign direct investment, renewable energy usage, and urban population in Vietnam over the period from 1990 to 2018 using the Environment Kuznets Curve. An autoregressive distributed lag bounds testing technique for measuring integration is utilized to investigate the long-run relationship. Results indicate that economic growth increases with CO_2 emissions until a certain threshold level and then CO_2 emissions decrease, thereby supporting the environmental Kuznets curve theory for Vietnam. Furthermore, this study examines the causal relationship among variables using a Granger causality model and determines that FDI, urban population, and renewable energy consumption play an important role and have substantial impact on carbon emission in Vietnam.

1. Introduction

In recent years, Vietnam's economy has sustained high growth rates, thereby resulting in favorable conditions for industrialization, modernization, poverty reduction, and job creation. However, along with its benefits, economic growth has placed tremendous pressure on environmental quality. The negative effects on environmental quality were more obvious in Vietnam in the early 2000s, when the pressure of increasing per capita income and the role of foreign direct investment (FDI) still exercised a substantial influence on economic growth. Nonetheless, there have been a number of significant environmental disasters recently, which have "awakened" state management organizations, enterprises, and citizens to the need to protect the environment. Further, energy consumption is another factor contributing to Vietnam's rising environmental degradation, thereby adding to foreign direct investment projects [1].

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The connection between economic growth or level of income and environmental decline, as shown by the hypothesis on the environmental Kuznets curve (EKC), is complicated. The EKC was first mentioned in the World Bank's World Development Report [2]. Grossman; Krueger [3] examined the connection between environmental damage and economic growth after being inspired by Kuznets [4], who described the association between income disparity and economic growth using an inverted U-shaped curve. They claimed that during the initial phases of growth, environmental contamination initially rises with an increasing per capita gross domestic product (GDP). In the later phases of development, this trend reverses, with environmental pollution levels declining and per capita income levels rising. This has led to the theory of the conventional EKC, which envisages an inverse U-shaped relationship between growth and pollution. Many studies have been conducted to either support or refute this theoretical connection. Due to different methodological techniques, time frames, and the inclusion (or absence thereof) of significant variables that might impact this association, results may differ among studies. Despite problems with EKC studies, there is scope to determine the bias caused by missing variables in the carbon emissions-to-income connection.

Beside, according to the European Environment Agency (EEA) [5], renewable energy is an important factor in reducing greenhouse gas (GHG) emissions. Richmond; Kaufmann [6] were among the first to incorporate renewable energy consumption (REC) in the EKC modeling approach. Nguyen et al. [7] and Nguyen and Le [8] found that REC reduced GHG emissions in Vietnam.

Anwar et al. [9] and Chen et al. [10] stressed the significance of the urban population in determining CO_2 emissions levels. Liu et al. [11] and Tang; Tan [12] incorporated FDI as a critical factor that may considerably affect emissions. There are few studies examining the impact of FDI, urban population, and REC on environmental performance using the EKC hypothesis in Vietnam. For these reasons, this study will add several variables included in the EKC literature, such as urban population and foreign direct investment. Hence, this study adds to the larger corpus of knowledge by interrogating the causal relationships among real GDP, CO_2 emissions, REC, FDI, and urban population in Vietnam.

This study aims to examine whether the EKC curve exists in Vietnam from 1990 to 2018 and the findings of this study will help answer "whether the using of renewable energy has an impact on environment and economic growth in Vietnam" and evaluate the long-run relationship between Vietnam's CO_2 emissions and economic growth using the autoregressive distributed lag (ARDL) model created by Pesaran et al. [13] with data collected between 1990 and 2018 and utilizes the Granger causality test with an error correction model to assess the causative linkages between variables in the long and short run [14]. Based on the empirical results, this study will contribute to the development of a sound policy framework and effective energy planning strategies during Vietnam's transition to a low-carbon development path. To develop effective economic and environmental policies, it is important to understand the connection between economic development and CO_2 emissions.

This study is divided into five sections. The first section which provides the introduction, whereas the second provides a literature review of extant studies concerning the association between GDP per capita and CO_2 emissions, including relevant aspects of FDI, urban population, and REC. The third section explains the research methodology of this study, and the fourth provides the results and a discussion of the findings. Finally, the fifth section provides a conclusion.

2. Literature review

The EKC hypothesis predicts a complicated link between growing incomes or economic expansion and environmental deterioration. Although EKC theory has drawn significant attention in the literature, its validity and predictive power remain debated. Owing to different methodologies, time frames, and the inclusion or exclusion of significant variables that may impact relationships, the results have varied greatly [15,16].

Economic growth, energy consumption, FDI, and increasing urbanization rates are considered to be the causes of negative environmental impacts [17]. Hence, this literature review divides the assessment of the relationships among energy use, CO_2 emissions, FDI, GDP, and the urban population into three parts. First, using actual data, the validity of the EKC hypothesis is evaluated regarding the relation between GDP and CO_2 emissions. Second, the energy–FDI–CO2 emissions nexus paradigm is examined. Third, the energy–CO_2 emissions–urban population nexus is examined.

Addressing the first approach, multiple studies have explored the occurrence of EKC-predicted behaviors in various nations and found mixed results caused by differences in polluting agents, research locations, time frames, and statistical methods [3]. Recent empirical EKC validity findings seem to conflict. For instance, Lean; Smyth [18] used a panel vector error correction model examination of the EKC to check the link between CO_2 emissions and economic development in five Association of Southeast Asian Nations (ASEAN) states. According to the empirical results, which are founded on annual data from 1980 to 2006, there appears to be support for the EKC hypothesis in the five ASEAN states. Between 1981 and 2011, Al-Mulali et al. [19] evaluated the EKC theory in Vietnam, finding it invalid due to the long- and short-term positive correlations between GDP and pollution. Additionally, REC was found to have no impact on the decrease in pollution, whereas the use of fossil fuels leads to increased pollution. Bölük; Mert [20] explored the connection between renewable energy-generated power, CO_2 emissions, and GDP in Turkey from 1961 to 2010. The results showed that the development of renewable electricity helps the environment with a one-year lag. Additionally, a U-shaped EKC association between income and per capita GHG emissions was found.

Addressing the second approach, many studies have demonstrated that encouraging energy consumption, attracting foreign direct investment, and economic expansion will all have negative affects on the environment. Alfaro et al. [21] claim that decision-makers always think FDI is a significant influence in raising the productivity of the host nation. This study also emphasizes the fact that FDI boosts power consumption efficiency through knowledge transfer and industry restructuring. Shahbaz; Lean [22] concluded that through the stimulation of economic activity, stock-market efficiency, and the attraction of FDI, emissions increase. Bakhsh et al. [23] found that FDI impacts environmental pollution in Pakistan through size, technique, and composition channel impacts, using yearly data from 1980 to 2014. The results of the technique and composition impacts indicated that increased economic growth results in higher pollution emissions. The scale effect showed that, although pollution has a detrimental influence on Pakistan's economic growth, the stock of labor and capital has a favorable impact. FDI was also found to have a significant and negative impact on renewable waste and CO_2 emissions. Omri et al. [24] found bidirectional causation between FDI flows and economic growth, as well as, between FDI and CO_2 emissions, suggesting that FDI might be harmful to host economies. According to studies concentrating on the Gulf Cooperation Council and ASEAN-5, economic development and energy use are drivers of pollution emissions, while FDI flows have little influence [25]. As a result, Pakistan's economy lacks an objective focus, and the outcome of FDI inflows on host nation pollution remains a disputed topic. Tang; Tan [12] used Granger causality to examine the relationships between energy use, CO_2 emissions, FDI, and economic development in Vietnam from 1976 to 2009. The relationships were found to be consistent with EKC, which postulates an inverted U-shaped association between economic development and CO_2 emissions. The results also demonstrated that there exists a two-way causal relationship between FDI and CO_2 emissions, as well as between CO_2 emissions and income. In Vietnam, FDI, energy consumption, and income are the key contributors to CO_2 emissions. The link between pollution and FDI in the five ASEAN states was also examined by Merican et al. [26]. Using the autoregressive distributive lag estimation, their results showed that FDI causes emissions to increase in the Philippines, Malaysia, and Thailand; however, there appears to be an inverse relationship between pollution and FDI in Indonesia. A dynamic analysis of the effects of FDI, international commerce, renewable energy, and technological innovation on China's CO_2 emissions from 1995 to 2017 was conducted by Liu, Wahab, Hussain, Sun, Kirikkaleli [11]. The results indicated that all models used in the study exhibited a cointegration relationship, suggesting that FDI and GDP have a positive impact on CO_2 emissions. The EKC hypothesis was also examined by Pao et al. [27], who used a panel cointegration approach for Brazil, India, China, and Russia from 1980 to 2007. They revealed a strong bidirectional causality existing between FDI and emissions, as well as, strong unidirectional causality from FDI to output and from energy usage to CO_2 emissions.

Addressing the third approach, urbanization is seen as a factor in the decrease of many ecosystems' quantity and quality, much like economic expansion. Major cities have evolved into hubs of economic activity, politics, education, and culture in many developing countries due to the constant economic growth, globalization, and work opportunities in city centers [28]. Particularly, the speed of urbanization has recently impacted the already limited supply of resources with detrimental effects on nations' environmental circumstances [29]. Urbanization plays a major role in the emissions–economic growth nexus, as implied by EKC theory. In the discussion of urbanization and environmental factors, the research of Glaeser; Kahn [30] is regarded as pioneering. They and others have argued that as urban populations grow, the environmental conditions of many cities worsen [31]. Some studies have demonstrated the importance of bringing urbanization into the relationship between CO_2 emissions, economic growth, and renewable energy. York et al. [32] agreed that urbanization increases CO_2 emissions for a group of 137 countries. Hossain [33] examined how urbanization, economic growth, energy consumption, CO_2 emissions, and trade are related in newly industrialized countries from 1971 to 2007; results disclosed that urbanization hurt CO_2 emissions and that there was no long-run relationship between variables. Nevertheless, there was a unidirectional short-run association between economic growth and urbanization. Similarly, Wang et al. [34] used a modified panel-based ordinary least squares technique to investigate the links among energy usage, urbanization, and CO_2 emissions in ASEAN nations. Results demonstrated a statistically significant positive connection between energy use and CO_2 emissions over time. Ali et al. [35] found that Pakistan's rapid urbanization is a key factor in the country's rising CO_2 emissions. Anwar et al. [9] performed an intriguing investigation, finding that urbanization has a favorable effect on CO_2 emissions in a sample of Asian economies, as supported by empirical evidence. Sun et al. [36] investigated the links among REC, urbanization, CO_2 emissions, and income in North Africa and the Middle East from 1991 to 2019. Long-term results that employ continuously updated longitudinal data with continuously updated bias-corrected techniques continue to point to the validity of EKC theory. Additionally, fast urbanization and economic growth are well-known to be associated with higher CO_2 emissions, whereas REC is known to be the most effective approach to decreasing CO_2 emissions. Martínez-Zarzoso; Maruotti [37] examined the effect of urbanization on CO_2 emissions in developing states from 1975 to 2003 and demonstrated that an inverted U-shaped pattern exists in the relationship between CO_2 emissions and urbanization.

The inconsistent findings of earlier research on the impact of energy use, foreign direct investment, urbanization, and economic growth on the quality of the environment has shown that these findings cannot be mechanically applied to Vietnam. Research results are different due to omitting variables or using different methods and various periods. We used urban population and FDI because since 1986, the process of industrialization has been accelerated, urban population increased from 20% in 1986 to 37% in 2019 [38] and FDI inflows increased from 40,000 USD to 16.12 billion USD in 2019 [39]. Therefore, this study incorporates the variables REC, urbanization, and FDI inflows in the same model that are expected to play a key role in the EKC approach.

These studies discovered several gaps in the literature. First, although Vietnam has actively encouraged economic growth over the past 30 years, most studies have only studied the effects of energy consumption on CO_2 emissions; few studies examine the relationship between GDP, CO_2 emissions and renewable energy consumption using the EKC theory to explain variables as urbanization and FDI. Most studies have only studied the effects of energy consumption on CO_2 emissions in Vietnam.

Moreover, this study has several benefits over earlier ones. It seeks to prevent the bias caused by missing variables by including FDI and the total urban population in the model. Addressing the methodological issues, the long-run connection is investigated using the autoregressive distributed lag bounds testing approach. Menegaki [40] suggests that one of the most adaptable techniques in the econometric study of the energy-growth nexus is the ARDL method. The Granger causality tests are then performed to determine the direction of the causal link between the variables. In addition to these benefits, this advanced method enables the capture of causal relationships in the short- and long-term.

3. Data and methodology

This study provides a broader lens to examine the relationship between economic growth and environmental damage with the participation of different economic variables such as CO_2 emissions is chosen because it is the most common parameter to predict emissions [3] and FDI, urban population are explain variables in the model.

The study uses annual data about Vietnam were collected from the World Bank covering the years 1990–2018, including GDP per capita (constant 2015 USD) [41], CO_2 emissions (metric tons per capita) [42], urban population (number of people) [43], FDI, net inflows (current USD) [39]. REC in quadrillions of British thermal units was taken from the U.S. Energy Information Administration [44].

The causal and long-run relationships between CO_2 emissions, GDP per capita, REC, urban population, and FDI are accomplished in two stages. We start by testing the long-run associations among the variables employing the ARDL bounded testing method of cointegration. Thereafter, we tested the causal linkages using the error correction-based causality models.

Follow the studies of Sharma [45], Hossain [33] shows the importance of urbanization in quality of environment, the study proposed equation (1), which provides a model of CO_2 emissions being decided by GDP, REC, urban population, and FDI as follows:

$$CO = AGDP^{\alpha_1} REC^{\alpha_2} UR^{\alpha_3} FDI^{\alpha_4} \tag{1}$$

Taking the natural logarithm of Equation (1) renders the equation as Equation (2):

$$\ln CO = \alpha_0 + \alpha_1 \ln GDP + \alpha_2 \ln REC + \alpha_3 \ln UR + \alpha_4 \ln FDI \tag{2}$$

The following model is used to test whether the EKC hypothesis holds when REC, the urban population, and FDI are included:

$$\ln CO_t = \alpha_0 + \alpha_1 \ln GDP_t + \alpha_2 \ln GDP_t{}^2 + \alpha_3 \ln REC_t + \alpha_4 \ln UR_t + \alpha_5 \ln FDI_t + \varepsilon_t \tag{3}$$

where t and ε are the time and white terms, respectively. CO represents CO_2 emissions per capita, UR is the urban population, and α_i, where i = 1, …, 5, is the long-run elasticity of GDP, GDP2, REC, UR, and FDI, respectively. In Equation (3), if $\alpha_1 > 0$ and $\alpha_2 < 0$, EKC holds. Therefore, this confirms the existence of an inverted U-shaped outline, which means that when GDP rises, CO_2 emissions also rise until GDP per capita reaches a threshold level. Then, CO_2 emissions start to decline as the GDP rises.

3.1. ARDL model

This study applies the ARDL model bounds testing method to cointegration, which was proposed by Pesaran and Shin [46] and enhanced by Pesaran, Shin; Smith [13]. However, before estimating the model, we must test for the existence of a unit root to guarantee that all variables are satisfied by ARDL assumptions. That is, all variables must be integrated at I(0) or I(1), or there must be mixed results; they must not be integrated at I(2). To achieve this, the study utilized the Augmented Dickey–Fuller (ADF) test from the work of Park; Fuller [47] and Phillips-Perron (PP) test by Phillips and Perron [48]. The ARDL bounds testing method takes two phases to evaluate the link in the long run. First, to test the long-run association between the variables in Equation (3), the ARDL model is designed as follows:

$$\begin{aligned}\Delta\ln CO = \beta_0 &+ \sum_{i=1}^{a_1}\beta_1\Delta\ln CO_{t-i} + \sum_{j=0}^{b1}\beta_2\Delta\ln GDP_{t-j} + \sum_{k=0}^{c1}\beta_3\Delta\ln GDP^2_{t-k} + \sum_{p=0}^{d1}\beta_4\Delta REC_{t-p} + \sum_{q=0}^{e1}\beta_5\Delta\ln UR_{t-q}\\ &+ \sum_{g=0}^{g1}\beta_6\Delta\ln FDI_{t-g} + \beta_6\ln CO_{t-1} + \beta_7\ln GDP_{t-1} + \beta_8\ln GDP^2_{t-1} + \beta_9\ln REC_{t-1} + \beta_{10}\ln UR_{t-1} + \beta_{11}\ln FDI_{t-1} + \mu_t\end{aligned} \tag{4}$$

where Δ is the initial difference term, and μ_t is the white-noise term. An appropriate lag is selected grounded on the Akaike information criterion (AIC) or the Schwarz–Bayesian criterion (SBC). To interrogate the joint significance of the null hypothesis without cointegration ($\beta i = 0; \forall i = 6, \ldots, 11$) against the alternative hypothesis ($\beta i \neq 0; \forall i = 6, \ldots, 11$), the bounds testing method to cointegration directs us to conduct the F-test on the chosen ARDL models. If the F-statistic is larger than the upper critical value, the null hypothesis is rejected, indicating cointegration. If it falls lower than the upper critical value, then there is no cointegration. If it falls between the lower and upper critical values, the findings become inconclusive.

The subsequent phase entails a general error rectification depiction of the selected ARDL model of Equation (4), as follows:

$$\begin{aligned}\Delta\ln CO = \beta_0 &+ \sum_{i=1}^{a_1}\beta_1\Delta\ln CO_{t-i} + \sum_{j=0}^{b1}\beta_2\Delta\ln GDP_{t-j} + \sum_{k=0}^{c1}\beta_3\Delta\ln GDP^2_{t-k} + \sum_{p=0}^{d1}\beta_4\Delta REC_{t-p} + \sum_{q=0}^{e1}\beta_5\Delta\ln UR_{t-q}\\ &+ \sum_{g=0}^{g1}\beta_6\Delta\ln FDI_{t-g} + \varphi ECT_{t-1} + \mu_t\end{aligned} \tag{5}$$

where ø denotes the error correction coefficient (ECT), and ECT_{t-1} is the lagged residuals attained from the projected long-run cointegration [Equation (3)]. At this phase, we must resolve to detach the lagged residuals from Equation (5) and define it as Equation (6):

$$ECT_{t-1} = \ln CO_{t-1} - \widehat{\alpha}_1 \ln GDP_{t-1} - \widehat{\alpha}_2 \ln GDP^2_{t-1} - \widehat{\alpha}_3 \ln REC_{t-1} - \widehat{\alpha}_4 \ln UR_{t-1} - \widehat{\alpha}_5 \ln FDI_{t-1} \tag{6}$$

The ECT coefficient should be statistically significant and have a negative sign. Thus, it demonstrates how rapidly the variables reach equilibrium.

3.2. Causality analysis

If a long-term association exists between variables, then the following step is to examine the causality between them. The ARDL model fails to show the direction of causation. Hence, after cointegration is established, the long-run model in Equation (3) is used to calculate the estimated residuals. Then, the Granger causality model [14] is used to estimate the error correction. The following model shows the causal relationships between the parameters:

$$\begin{bmatrix} \Delta\ln CO \\ \Delta\ln GDP \\ \Delta\ln GDP2 \\ \Delta\ln REC \\ \Delta\ln UR \\ \Delta\ln FDI \end{bmatrix} = \begin{bmatrix} \mu_1 \\ \mu_2 \\ \mu_3 \\ \mu_4 \\ \mu_5 \\ \mu_6 \end{bmatrix} + \begin{bmatrix} \pi_{11,1} & \pi_{12,1} & \pi_{13,1} & \pi_{14,1} \\ \pi_{21,1} & \pi_{22,1} & \pi_{23,1} & \pi_{24,1} \\ \pi_{31,1} & \pi_{32,1} & \pi_{33,1} & \pi_{34,1} \\ \pi_{41,1} & \pi_{42,1} & \pi_{43,1} & \pi_{44,1} \\ \pi_{51,1} & \pi_{52,1} & \pi_{53,1} & \pi_{54,1} \\ \pi_{61,1} & \pi_{62,1} & \pi_{63,1} & \pi_{64,1} \end{bmatrix} \begin{bmatrix} \Delta\ln CO_{t-1} \\ \Delta\ln GDP_{t-1} \\ \Delta\ln GDP2_{t-1} \\ \ln REC_{t-1} \\ \Delta\ln UR_{t-1} \\ \Delta\ln FDI_{t-1} \end{bmatrix} + \dots$$
$$+ \begin{bmatrix} \pi_{11,n} & \pi_{12,n} & \pi_{13,n} & \pi_{14,n} \\ \pi_{21,n} & \pi_{22,n} & \pi_{23,n} & \pi_{24,n} \\ \pi_{31,n} & \pi_{32,n} & \pi_{33,n} & \pi_{34,n} \\ \pi_{41,n} & \pi_{42,n} & \pi_{43,n} & \pi_{44,n} \\ \pi_{51,n} & \pi_{52,n} & \pi_{53,n} & \pi_{54,n} \\ \pi_{61,n} & \pi_{62,n} & \pi_{63,n} & \pi_{64,n} \end{bmatrix} \begin{bmatrix} \Delta\ln CO_{t-n} \\ \Delta\ln GDP_{t-n} \\ \Delta\ln GDP2_{t-n} \\ \Delta\ln REC_{t-n} \\ \Delta\ln UR_{t-n} \\ \Delta\ln FDI_{t-n} \end{bmatrix} + \begin{bmatrix} \psi_1 \\ \psi_2 \\ \psi_3 \\ \psi_4 \\ \psi_5 \\ \psi_6 \end{bmatrix} ECT_{t-1} + \begin{bmatrix} \varepsilon_4 \\ \varepsilon_5 \\ \varepsilon_6 \\ \varepsilon_7 \\ \varepsilon_8 \\ \varepsilon_9 \end{bmatrix} \tag{7}$$

where ε_{4t}, ε_{5t}, ε_{6t}, ε_{7t}, ε_{8t}, and ε_{9t}, are normally and independently distributed with a constant variance. n is the optimal lag length, which is determined using the AIC or SBC criterion. Using Equation (7), this study explores the causality relationship in two ways. First, the F-statistic or Wald test finds the relevant π coefficient's significance on the first-differenced series to assess causality in the short run. Second, t- or Wald tests are used to find the relevant Ψ coefficient's significance on the lagged ECT to detect causality in the long run. If the error correction term is statistically significant with a negative sign, it signifies long-run causality.

Brown et al. [49] developed CUSUM-of-squares (CUSUMSQ) and cumulative sum (CUSUM) tests founded on recursive regression residuals. The plots of these statistics are found within the critical bounds; thus, the coefficients of regression are stable.

4. Results and discussion

Before implementing the ARDL approach, this study tested the order of integration using the ADF test to ensure that all variables were not integrated at I(2). The ADF test and PP test indicated mixed results of stationarity (Tables 1 and 2), and all variables were integrated at I(1) or I(0) and were not stationary at I(2). Therefore, this study could be used with ARDL methodology to investigate the presence of long-run links between variables. This study used AIC to determine the optimal lag length, and the data showed that lag 2 was the optimal length.

The bounded F-test resulted in 12.07, which is more than the upper bound at a 5% significance level. This indicates that cointegration exists in this model. Table 3 displays the long-term associations among the variables. According to the EKC hypothesis, it is expected that the long-run elasticity estimates of GDP2 are negative and CO_2 emissions per capita to GDP per capita are projected to be positive. Thus, increasing GDP per capita by 1% can increase CO_2 emissions per capita by 3.23%, whereas increasing GDP2 by 1% reduces CO_2 emissions per capita by 0.4%. These findings support the EKC theory's validity in the Vietnamese economy. In the early

Table 1
ADF test results.

Variable	Level		First differences	
	Prob. (with trends)	Intercept	Prob. (with trends)	Intercept
CO	0.8442	0.6247	0.0013*	0.0003*
GDP	0.0569***	0.7419	0.2024	0.0795***
GDP2	0.0179**	0.9552	0.1946	0.0524***
REC	0.1917	0.9555	0.0001*	0.0000*
UR	0.1367	0.5418	0.0958***	0.0413**
FDI	0.0973***	0.6376	0.0305**	0.0057*

Note: CO = carbon emissions; GDP = gross dFomestic product; GDP2 = square of GDP, REC = renewable energy consumption; UR = urban population; FDI = foreign direct investment. *, **, and *** indicate significance at the 1%, 5%, and 10% levels, respectively.

Table 2
PP test results.

Variable	Level		First differences	
	Prob. (with trends)	Intercept	Prob. (with trends)	Intercept
CO	0.6620	0.5781	0.0000*	0.0002*
GDP	0.8773	0.6203	0.0565***	0.0305**
GDP2	0.6498	0.9734	0.0714***	0.0174**
REC	0.1941	0.9222	0.0000*	0.0000*
UR	0.0001*	0.0127**	0.3498	0.0854***
FDI	0.2071	0.2700	0.0322**	0.0060*

Note: CO = carbon emissions; GDP = gross dFomestic product; GDP2 = square of GDP, REC = renewable energy consumption; UR = urban population; FDI = foreign direct investment. *, **, and *** indicate significance at the 1%, 5%, and 10% levels, respectively.

Table 3
Long-run relationship.

Variable	Coefficient	Std. Error	t-Statistic	Probability
GDP	3.2371**	1.2002	2.6970	0.0166
GDP2	−0.4070**	0.1036	−3.9258	0.0013
REC	−0.4169**	0.1042	−3.9985	0.0012
FDI	0.1010**	0.0370	2.7256	0.0156
UR	6.6315**	2.1454	3.0910	0.0075
Intercept	−118.7208**	30.6069	−3.8788	0.0015

** Significant at a 5% level.

stages of industrialization, for developing countries like Vietnam, there will be a trade-off between economic growth and environmental quality because environmental protection is not a priority in this process of national action plan. However, in the later stages of industrialization, along with rising income levels, people put more importance on environmental issues and governing bodies became more efficient, resulting in less environmental pollution. Consumers with higher income levels are willing to spend more on green and clean products and pay more attention to environmental protection and regulations.

Moreover, the coefficients of FDI and urban population are also positive at a 5% significance level. Thus, a 1% surge in FDI results in a rise in CO_2 emissions per capita by 0.1%, and a 1% surge in urban population causes an increase of CO_2 emissions per capita by 6.63%. However, a 1% rise in REC leads to a reduction in per capita CO_2 emissions by 0.41% (significant at the 5% level).

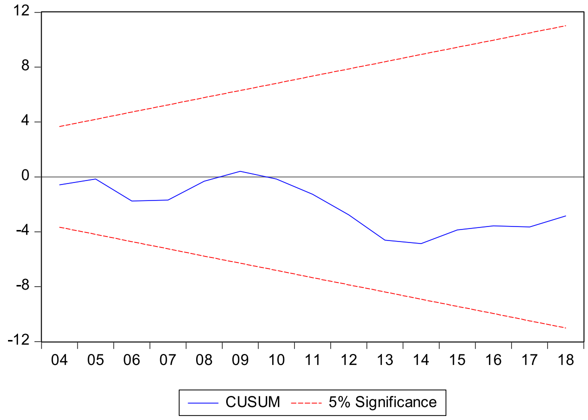
Calculated ECT coefficients were negative (−0.82) and statistically significant at a 1% confidence level. These values show that any nonconformity from the long-run equilibrium between variables is amended for each period and leads to the reoccurrence of a long-run level of equilibrium.

To check for parameter constancy, the cumulative sum of squares (CUSUMSQ) and cumulative sum (CUSUM) instability tests founded on recursive residuals were applied. These tests were created by Brown et al. [49], who noted that although regression coefficients are constant under the null hypothesis, they vary under the alternative hypothesis. Fig. 1a and b present the CUSUM and CUSUMSQ graphs. The lines fall between the critical bounds; thus, the results affirm that the coefficients of regression are stable.

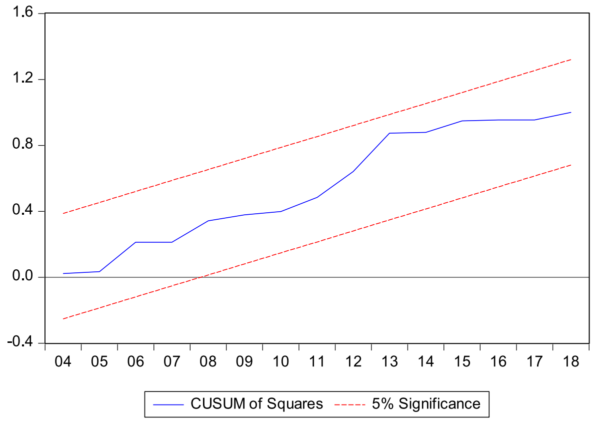
The results from both models of Granger causality are reported in Table 4 and compiled as follows. First, there is an indication of a two-way causal association between GDP, REC, FDI, and urban population to CO_2 emissions in the short and long runs. This result shows that when FDI, urban population, economic growth, or clean energy increase, CO_2 emissions will increase. This result agrees with the empirical results of Bölük; Mert [20] and Sulaiman, Azman, and Saboori [50], who respectively found that clean energy use decreased emissions in Turkey and Malaysia. Moreover, the results show that urban populations are important to CO_2 emissions, which is consistent with Parikh; Shukla [51], York, Rosa; Dietz [32], and Al-Mulali et al. [52].

Second, there is unidirectional causality from FDI to CO_2 emissions, thereby showing that FDI plays an important role in environmental quality. These results align with Shahbaz; Lean [22] and Omri et al. [24], who found that FDI hurts the environment. Governments should encourage foreign investment while protecting the environment; in the future, the strengthening of standards and technical controls on goods, the environment, and resources will be required to save energy and cut emissions according to national and international standards. In the establishment of legislative documents and policies relating to environmental emissions, a focus should be placed on encouraging businesses to adopt effective emissions reduction plans or preferred policies to employ low-emissions technology and processes. Hence, the government needs to be very careful when selecting foreign investors, as well as fully assess the environmental impacts of FDI projects before, during and after the investment process.

Third, there is a bidirectional link between dioxide emissions and REC, but no causality was detected between REC and economic growth in the short run. However, there is a unidirectional relationship between GDP and REC in the long term. This implies that as GDP increases, more energy is consumed, and clean energy is favorable to emissions and will promote GDP in the long run and vice versa. As a result, a nation's economy need not be boosted solely by energy consumption. Therefore, the link suggests that energy policies like carbon emission reduction, energy efficiency measures won't decrease the rate of economic expansion.



a



b

Fig. 1. (a) Graph of CUSUM.(b) Graph of CUSUMSQ.

Table 4
Short- and long-run causality.

Variable	Short-run causality F-statistic (probability)						Long-run causality ECTt – 1 (t-statistic)
	ΔCO	ΔGDP	ΔGDP2	ΔREC	ΔFDI	ΔUR	
ΔCO	–	5.931 (0.0126) **	5.913 (0.0128) **	22.170 (0.0003)*	6.583 (0.0089) *	11.752 (0.0008)*	−0.8277 (−10.608)*
ΔGDP	5.6283 (0.0173)**	–	5603.7 (0.0000)*	2.0242 (0.1717)	17.6399 (0.0002)*	12.996 (0.0003)*	0.027 (0.0000)*
ΔGDP2	5.5552 (0.0180)**	6792.414 (0.000)*	–	1.92755 (0.1849)	17.300 (0.0002)*	16.9330 (0.0002)*	0.00419 (0.0000)*
ΔREC	23.979 (0.0005)*	1.4630 (0.2781)	1.8815 (0.1912)	–	3.6711 (0.0471)**	8.0086 (0.0041)*	−1.219 (0.0000)*
ΔFDI	2.4690 (0.1120)	1.3526 (0.3039)	0.9464 (0.4489)	2.8560 (0.0816)	–	0.1855 (0.6743)	−0.664 (0.0001)*
ΔUR	2.3727 (0.1354)	1.7791 (0.2105)	3.9179 (0.0367)**	3.8614 (0.0382)**	1.0294 (0.3867)	–	No cointegration

Note: *, **,***: significant at 1%, 5%, 10%.

5. Conclusion

The findings of this study demonstrate causal relationships among FDI, economic growth, REC, CO_2 emissions, and the urban population in Vietnam. For Vietnam, the validity of an inverted U-shaped EKC is supported. We employed the ARDL bounded testing technique to investigate the links among REC, economic growth, CO_2 emissions, FDI, and urban populations. Results also emphasize that REC, the urban population, and FDI are vital in reducing CO_2 emissions. Empirical results have made certain contributions to the theory of the impact of renewable energy consumption on other macro variables.

This study provides evidence of the bidirectional causality between CO_2 emissions and GDP in the short and long term. In Vietnam, the long- and short-term dynamics of CO_2 emissions are significantly negatively impacted by REC. Therefore, the Vietnamese government should focus on policies that promote the use of clean energy, which is less harmful to the environment, and sustainable growth, because there are huge potential sources of clean energy in Vietnam. Moreover, the high cost of renewable energy in comparison to fossil fuel electricity is one of the main obstacles currently present. Thus, renewable energy prices in Vietnam should accurately represent their socioeconomic advantages.

Policymakers in Vietnam should carefully manage the FDI inflows for manufacturing operations to accurately analyze the balance between economic profit and environmental damage, since our estimation results also demonstrate that FDI has a favorable influence on economic growth in Vietnam. The host economy is anticipated to benefit from FDI inflows by gaining the use of modern, environmentally friendly technology. We thus propose that the Vietnamese government provide funds and implement measures to attract foreign investment. This would enable the development and implementation of more effective and low-carbon technology across all industries, ultimately promoting economic growth in Vietnam.

Because the urban population plays an important role in CO_2 emissions, policymakers should enhance the nation's public transportation network and environmental quality. The government needs to calculate the urbanization rate in accordance with the urban planning. Practice in developed countries shows that the process of urbanization is only really successful when it does not change or increase. people's living standards in terms of green space, transport infrastructure, air quality or the development of health care systems, schools, in addition to other minimum conditions such as clean water supply, food and security.

This study has some limitations such time period of study was short and the data were annual. This can be affect to research result. Beside the study only examines CO_2 emissions, which is a key contributor to GHG. However, future studies should expand research to other gases, such as nitrogen dioxide and methane, and other environmental factors, such as health impacts and waste, regarding their effects on income. Moreover, data on urban population and FDI inflow are generally aggregate data, so the study does not specify which province or city is the source of increased environmental pollution, this is also a suggestion for future research directions.

Author contribution statement

Thuy Bui Minh: Conceived and designed the experiments; performed the experiments; analyzed and interpreted the data; contributed reagents, materials, analysis tools or data; wrote the paper.

Toan Nguyen Ngoc and Huyen Bui Van: Contributed reagents, materials, analysis tools or data.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

References

[1] M. Ha-Duong, H.A. Nguyen-Trinh, Two scenarios for carbon capture and storage in Vietnam, Energy Pol. 110 (2017) 559–569, https://doi.org/10.1016/j.enpol.2017.08.040.
[2] B. World, World Development Report, Oxford University Press, New York, 1992.
[3] G. Grossman, A.B. Krueger, Environmental Impacts of a North American Free Trade Agreement, 1991, https://doi.org/10.3386/w3914. NBER Working Paper no. 3914.
[4] S. Kuznets, Economic growth and income inequality, Am. Econ. Rev. 45 (1955) 1.
[5] Executive Office of Energy and Environmental Affairs, Progress towards 2008–2012 Kyoto Targets in Europe, in: European Environment Agency (EEA) Technical Report, No. 18/2014, 2014. http://www.eea.europa.eu/publications/progress-towards-2008-2012-kyoto.
[6] A.K. Richmond, R.K. Kaufmann, Is there a turning point in the relationship between income and energy use and/or carbon emissions? Ecol. Econ. 56 (2006) 176–189, https://doi.org/10.1016/j.ecolecon.2005.01.011.
[7] H.T. Nguyen, S.V. Nguyen, V. Dau, A.T.H. Le, K.V. Nguyen, D.P. Nguyen, et al., The nexus between greenhouse gases, economic growth, energy and trade openness in Vietnam, Environ. Technol. Innov. 102912 (2022) 28, https://doi.org/10.1016/j.eti.2022.102912.
[8] V.C.T. Nguyen, H.Q. Le, Renewable energy consumption, nonrenewable energy consumption, CO_2 emissions and economic growth in Vietnam, MEQ 33 (2022) 419–434, https://doi.org/10.1108/MEQ-08-2021-0199.
[9] A. Anwar, A. Sinha, A. Sharif, M. Siddique, S. Irshad, W. Anwar, et al., The nexus between urbanization, renewable energy consumption, financial development, and CO_2 emissions: evidence from selected Asian countries, Environ. Dev. Sustain. 24 (2022) 6556–6576, https://doi.org/10.1007/s10668-021-01716-2.
[10] S. Chen, H. Jin, Y. Lu, Impact of urbanization on CO_2 emissions and energy consumption structure: a panel data analysis for Chinese prefecture-level cities, Struct. Change Econ. Dyn. 49 (2019) 107–119, https://doi.org/10.1016/j.strueco.2018.08.009.
[11] X. Liu, S. Wahab, M. Hussain, Y. Sun, D. Kirikkaleli, China carbon neutrality target: revisiting FDI-trade-innovation nexus with carbon emissions, J. Environ. Manag. 113043 (2021) 294, https://doi.org/10.1016/j.jenvman.2021.113043.
[12] C.F. Tang, B.W. Tan, The impact of energy consumption, income and foreign direct investment on carbon dioxide emissions in Vietnam, Energy 79 (2015) 447–454, https://doi.org/10.1016/j.energy.2014.11.033.

[13] M.H. Pesaran, Y. Shin, R.J. Smith, Bounds testing approaches to the analysis of level relationships, J. Appl. Econ. 16 (2001) 289–326, https://doi.org/10.1002/jae.616.
[14] R.F. Engle, C.W.J. Granger, Co-integration and error correction: representation, estimation, and testing, Econometrica 55 (1987) 251–276, https://doi.org/10.2307/1913236.
[15] M. Alam, W. Murad, A. Noman, I. Ozturk, Relationships among carbon emissions, economic growth, energy consumption and population growth: testing environmental Kuznets curve hypothesis for Brazil, China, India and Indonesia, Ecol. Indicat. 70 (2016) 466–479, https://doi.org/10.1016/j.ecolind.2016.06.043.
[16] R. Inglesi-Lotz, A. Pouris, On the causality and determinants of energy and electricity demand in South Africa: a review, Energy Sources B: Econ. Plan. Policy 11 (2016) 626–636, https://doi.org/10.1080/15567249.2013.801536.
[17] E. Dogan, R. Ulucak, E. Kocak, C. Isik, The use of ecological footprint in estimating the Environmental Kuznets Curve hypothesis for BRICST by considering cross-section dependence and heterogeneity, Sci. Total Environ. 723 (2020), 138063, https://doi.org/10.1016/j.scitotenv.2020.138063.
[18] H.H. Lean, R. Smyth, CO_2 emissions, electricity consumption and output in ASEAN, Appl. Energy 87 (2010) 1858–1864, https://doi.org/10.1016/j.apenergy.2010.02.003.
[19] U. Al-Mulali, B. Saboori, I. Ozturk, Investigating the environmental Kuznets curve hypothesis in Vietnam, Energy Pol. 76 (2015) 123–131, https://doi.org/10.1016/j.enpol.2014.11.019.
[20] G. Bölük, M. Mert, The renewable energy, growth and environmental Kuznets curve in Turkey: an ARDL approach, Renew. Sustain. Energy Rev. 52 (2015) 587–595, https://doi.org/10.1016/j.rser.2015.07.138.
[21] L. Alfaro, A. Chanda, S. Kaleml - i Ozcan, S. Sayek, “Does foreign direct investment promote growth? Exploring the role of financial markets on linkages”, J. Dev. Econ. 91 (2010) 242–256. http://doi:10.1016/j.jdeveco.2009.09.004.
[22] M. Shahbaz, H.H. Lean, Does financial development increase energy consumption? The role of industrialization and urbanization in Tunisia, Energy Pol. 40 (2012) 473–479, https://doi.org/10.1016/j.enpol.2011.10.050.
[23] K. Bakhsh, S. Rose, M.F. Ali, N. Ahmad, M. Shahbaz, Economic growth, CO_2 emissions, renewable waste and FDI relation in Pakistan: new evidences from 3SLS, J. Environ. Manag. 196 (2017) 627–632, https://doi.org/10.1016/j.jenvman.2017.03.029.
[24] A. Omri, D.K. Nguyen, C. Rault, Causal interactions between CO_2 emissions, FDI, and economic growth: evidence from dynamic simultaneous-equation models, Econ. Modell. 42 (2014) 382–389, https://doi.org/10.1016/j.econmod.2014.07.026.
[25] U. Al-mulali, C. Foon Tang, Investigating the validity of pollution haven hypothesis in the gulf cooperation council (GCC) countries, Energy Pol. 60 (2013) 813–819, https://doi.org/10.1016/j.enpol.2013.05.055.
[26] Y. Merican, Z. Yusop, Z.M. Noor, L.S. Hook, Foreign direct investment and the pollution in five ASEAN nations, Int. J. Econ. Manag. 1 (2007) 245–261.
[27] H. Pao, C. Tsai, Multivariate Granger causality between CO_2 emissions, energy consumption, FDI (foreign direct investment) and GDP (gross domestic product): evidence from a panel of BRIC (Brazil, Russian Federation, India, and China) countries, Energy 36 (2011) 685–693, https://doi.org/10.1016/j.energy.2010.09.041.
[28] B. Lin, J. Zhu, Changes in urban air quality during urbanization in China, J. Clean. Prod. 188 (2018) 312–321, https://doi.org/10.1016/j.jclepro.2018.03.293.
[29] J. Li, X. Huang, M.P. Kwan, H. Yang, X. Chuai, The effect of urbanization on carbon dioxide emissions efficiency in the Yangtze River Delta, China. J Cleaner Prod 188 (2018) 38–48, https://doi.org/10.1016/j.jclepro.2018.03.198.
[30] E.L. Glaeser, Kahn ME. The greenness of cities: carbon dioxide emissions and urban development, J. Urban Econ. 67 (2010) 404–418, https://doi.org/10.1016/j.jue.2009.11.006.
[31] W. Song, X. Deng, B. Liu, Z. Li, G. Jin, Impact of grain for green and grain for blue policies on valued ecosystem services in Shandong Province, China, Adv. Meteorol. 2015 (2015) 1–10, https://doi.org/10.1155/2015/213534.
[32] R. York, E.A. Rosa, T. Dietz, STIRPAT, IPAT, ImPACT: analytic tools for unpacking the driving forces of environmental impacts, Ecol. Econ. 46 (2003) 351–365, https://doi.org/10.1016/S0921-8009(03)00188-5.
[33] M.S. Hossain, Panel estimation for CO_2 emissions, energy consumption, economic growth, trade openness and urbanization of newly industrialized countries, Energy Pol. 39 (2011) 6991–6999, https://doi.org/10.1016/j.enpol.2011.07.042.
[34] Y. Wang, L. Chen, Kubota J.The relationship between urbanization, energy use and carbon emissions: evidence from a panel of Association of Southeast Asian Nations (ASEAN) countries, J. Clean. Prod. 112 (2016) 1368–1374, https://doi.org/10.1016/j.jclepro.2015.06.041.
[35] R. Ali, K. Bakhsh, M.A. Yasin, Impact of urbanization on CO_2 emissions in emerging economy: evidence from Pakistan, Sustain. Cities Soc. 48 (2019), 101553, https://doi.org/10.1016/j.scs.2019.101553. Article.
[36] Y. Sun, H. Li, Z. Andlib, M.G. Genie, How do renewable energy and urbanization cause carbon emissions? Evidence from advanced panel estimation techniques, Renew. Energy 185 (2022) 996–1005, https://doi.org/10.1016/j.renene.2021.12.112.
[37] I. Martínez-Zarzoso, A. Maruotti, The impact of urbanization on CO_2 emissions: evidence from developing countries, Ecol. Econ. 70 (2011) 1344–1353, https://doi.org/10.1016/j.ecolecon.2011.02.009.
[38] B. World, Urban population (number of people). Vietnam. https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS?locations=VN, 2023 [Accessed 20 February 2023].
[39] World B. FDI, net inflows (current USD), 2022. Vietnam, https://data.worldbank.org/indicator/BX.KLT.DINV.CD.WD?locations=VN [Accessed 15 June 2022].
[40] A.N. Menegaki, The ARDL method in the energy-growth nexus field; best implementation strategies, Economies 7 (4) (2019) 1–16, https://doi.org/10.3390/economies7040105.
[41] B. World, GDP Per Capita (Constant 2015 USD). Vietnam, 2022. https://data.worldbank.org/indicator/NY.GDP.MKTP.KD?locations=VN [Accessed 15 June 2022].
[42] B. World, CO2 Emissions (Metric Tons Per Capita). Vietnam, 2022. https://data.worldbank.org/indicator/EN.ATM.CO2E.KT?locations=VN [Accessed 15 June 2022].
[43] B. World, Urban Population (Number of People). Vietnam, 2022. https://data.worldbank.org/indicator/SP.URB.TOTL?locations=VN [Accessed 15 June 2022].
[44] Energy U.S. Information Administration (EIA). Vietnam, 2022. Open Data, https://www.eia.gov/international/data/country/VNM/total-energy/total-energy-consumption?pd=44&p=0000000010000000000000000000000000000000000000000000000000u06&u=0&f=A&v=mapbubble&a=-&i=none&vo=value&vb=44&t=C&g=none&l=249–246&s=315532800000&e=1546300800000&ev=false [Accessed 15 June 2022].
[45] S.S. Sharma, Determinants of carbon dioxide emissions: empirical evidence from 69 countries, Appl. Energy 88 (2011) 376–382, https://doi.org/10.1016/j.apenergy.2010.07.022.
[46] H.M. Pesaran, Y. Shin, in: S. Storm (Ed.), Autoregressive distributed lag modelling approach to cointegration analysis, Econometrics and Economic Theory in the 20th Century: the Ragnar Frisch Centennial Symposium, Cambridge University Press, Cambridge, 1999.
[47] H.J. Park, W.A. Fuller, Alternative estimators and unit root tests for the autoregressive process, J. Time Ser. Anal. 16 (1995) 415–429, https://doi.org/10.1111/j.1467-9892.1995.tb00243.x.
[48] P.C.B. Phillips, P. Perron, Testing for a unit root in time series regression, Biometrika 75 (2) (1988) 335–346, https://doi.org/10.2307/2336182.
[49] R.L. Brown, J. Durbin, J.M. Evans, Techniques for testing the constancy of regression relationships over time, J. Roy. Stat. Soc. B 37 (1975) 149–163, https://doi.org/10.1111/j.2517-6161.1975.tb01532.x.
[50] J. Sulaiman, A. Azman, B. Saboori, The potential of renewable energy: using the environmental Kuznets curve model, Am. J. Environ. Sci. 9 (2013) 103–112, https://doi.org/10.3844/ajessp.2013.103.112.
[51] J. Parikh, V. Shukla, Urbanization, energy use and greenhouse effects in economic development, Global Environ. Change 5 (1995) 87–103, https://doi.org/10.1016/0959-3780(95)00015-G.
[52] U. Al-Mulali, H.G. Fereidouni, J.Y.M. Lee, C.N.B.C. Sab, Exploring the relationship between urbanization, energy consumption, and CO_2 emissions in MENA countries, Renew. Sustain. Energy Rev. 23 (2013) 107–112, https://doi.org/10.1016/j.rser.2013.02.041.