




# “Economic growth impact of climate change: New empirical evidence from Vietnam”

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# ECONOMIC GROWTH IMPACT OF CLIMATE CHANGE: NEW EMPIRICAL EVIDENCE FROM VIETNAM

## Abstract

This study aims to investigate the economic effect of climate change by providing rigorous evidence of its impact in the most climate-susceptible economies, with Vietnam as a representative case. The study scrutinizes the economic growth impact of climate change while examining the intervening roles of renewable energy usage, trade openness, and the interaction between renewable energy usage and financial development in both the short and long run. Applying the ARDL framework using Vietnam's data from 1992 to 2022, the results provide evidence that climate change exerts a direct influence on growth across both time horizons. Specifically, a one-degree Celsius increase in temperature is associated with an approximate 0.18% increase in GDP in the long run, and 0.018% in the short run. The findings suggest that greater reliance on renewable energy contributes positively to economic performance, as a 1% increase in the renewable energy share within the energy mix corresponds to a 1.1% expansion in GDP. In contrast, increased trade openness is found to adversely affect long-run growth, with a 1% rise in openness linked to a GDP contraction of about 0.004%. Furthermore, the joint effect of renewable energy utilization and financial development does not display a statistically significant influence on long-run growth. Conversely, short-run dynamics indicate that changes in this interaction support growth, while adjustments in renewable energy consumption and trade openness tend to dampen growth performance. The study recommends policies that enhance climate resilience, promote renewable energy, and support trade strategies to strengthen production value chains for sustainable growth.

## Keywords

climate change, economic growth, renewable energy,  
trade openness, Vietnam

## JEL Classification

O44, F43, Q54

## INTRODUCTION

Climate change has increasingly been recognized as a paramount challenge confronting nations worldwide. The intensified impacts of climate variability (increasing temperatures, irregular precipitation patterns, extended dry periods, water shortages, land deterioration, flooding, long-duration drought phenomena, and rising sea levels) on the economic trajectory of countries have become a worldwide concern. Countries largely influenced by climate change confront substantial difficulties and obstacles to achieving sustainable economic progress.

Vietnam is one of the countries most vulnerable to climate change due to its geographical location, complex topography, dense population distribution, and heavy reliance on climate-sensitive economic sectors. Different climate-induced disruptions are particularly critical for Vietnam, where large segments of the population and productive activities are concentrated in coastal zones, river deltas, and flood-prone areas.

At the same time, Vietnam's ongoing economic transformation, characterized by deeper integration into global trade networks, accelerated financial development, and a gradual transition toward renewable energy, has reshaped the channels through which climate change may influence growth outcomes. While renewable energy expansion is increasingly promoted as a pathway to reduce climate-related risks and ensure energy security, trade openness and financial development may either amplify or mitigate the economic consequences of climate variability. This complexity underscores a broader scientific problem: the economic growth impacts of climate change cannot be fully understood in isolation from the economic mechanisms and adjustment processes through which climate disturbances affect an economy. Clarifying this problem is essential for designing effective adaptation strategies and sustaining long-term economic development in climate-vulnerable economies.

Within this setting, climate change poses not only an environmental challenge but also a structural economic concern, as its effects on growth are mediated through evolving energy systems, increasing exposure to global markets, and the functioning of financial institutions. The simultaneous expansion of renewable energy use, trade integration, and financial activity introduces multiple channels through which climate-related fluctuations may influence economic performance, potentially altering both the magnitude and direction of growth responses. For a highly exposed economy such as Vietnam, these overlapping processes complicate the assessment of climate impacts and raise fundamental questions regarding how economic growth adjusts under persistent climate stress. Addressing this scientific problem is crucial for understanding the long-term growth implications of climate change in economies undergoing rapid transformation and facing heightened climate vulnerability.

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## 1. LITERATURE REVIEW

The link between climate change and economic growth has become an increasingly significant topic, owing to the heightened awareness of the multifaceted effects of climate change on sustainable economic advancement and human health. Extensive theoretical and empirical investigations have assessed the nexus between climate change and economic growth while incorporating the variables of renewable energy consumption, trade openness, and financial development. The literature surrounding this relationship is still developing.

### 1.1. Climate change and economic growth

Climate alterations influence growth in a variety of complex ways due to their long-term effects. Many scholarly materials have indicated that climate change might impede economic development. Agricultural production, forestry, tourism, energy, coastal resources, and infrastructure may be adversely influenced by extreme climatic events, changes in temperature and precipitation patterns, and rising sea levels. Macroeconomic effects encompass the influences on economic out-

put and the nation's economic growth trajectory (Dell et al., 2012). Economic development may be slowed by climate change, causing food shortages, price volatility, and reduced income for farmers. In addition, millions of people may face health consequences. This could lead to increased health-care costs and reduced labor productivity, both of which are recognized as barriers to growth.

The adverse economic growth effect of climate variations is reinforced by theoretical and empirical evidence. The most prevalent factors used to characterize climate change in studies are year-to-year temperature variability (Dell et al., 2012) and precipitation (annual cumulative amount of rainfall) (Dell et al., 2014). Adopting various plausible methods, empirical studies have confirmed that climate change can substantially impact the entire economy, especially for those whose economic activities are natural resource sensitive, such as agricultural activities. Utilizing a cross-national panel climate dataset, Barrios et al. (2010) suggested that rainfall trends have influenced growth in sub-Saharan Africa, although no similar relationship was observed in other developing countries. The overall reduction in precipitation has negatively affected sub-Saharan African nations' growth rates. For Ethiopia, Ali (2012) showed that both inter-

annual and within-annual rainfall variations have negative effects on growth.

Dell et al. (2012), employing data from 136 countries over the period 1950–2003, provided empirical evidence on the higher temperature effects on economic growth. First, it substantially reduces growth in low-income countries. Second, higher temperatures exert broad-ranging impacts, leading to declines in the output of agriculture and industry and also increasing political instability. Similarly, findings by Abidoye and Odusola (2015) demonstrated a detrimental growth effect of climate variability across 34 African economies from 1961 to 2009. Souvannasouk et al. (2021) indicated that rising temperatures negatively affected the GDP of ASEAN countries during 1995–2018. Baarsch et al. (2020) showed that, with historical average losses attributable to climate ranging from 10 to 15% of the growth in GDP per capita, most African economies exhibit insufficient adaptation to prevailing climatic conditions. Nations in the West and East of the African continent are predicted to be the most severely impacted. In sub-Saharan Africa, Alagidede and Adu (2014) emphasized the non-linear nexus between temperature and economic efficiency, with temperatures above 24.9°C significantly reducing growth.

However, other studies indicate that this linkage is more complicated and may vary across nations, contingent upon their development and vulnerability to climate change. For developed economies, the effects of climate change have been discerned as less severe due to natural advantages, better adaptation strategies, higher technology, more mechanized agricultural systems, and wealthier levels. The climate change impact on developing nations is highly significant due to elevated temperatures, limited adaptive capacity, and the absence of an early warning system.

According to Lamperti et al. (2021), constraints of finance aggravate the effect of climate-related shocks on the economy, whereas climate damage to companies makes the banking sector more susceptible. Adom and Amoani (2021) argued that rising temperature has a substantial negative impact on growth, with these effects being adjusted by the adaptation readiness degree through channels related to both output and institutions. Employing

data from 44 African economies in six distinct climatic areas spanning from 2000 to 2019, Zhao and Liu (2023) indicated that temperature exhibits an inverted U-shaped connection to the growth of nations within regions characterized by tropical rainforest and tropical dry climates, while showing a U-shaped impact across warm temperate humid zones. Furthermore, climate alteration positively influences growth in coastal areas but has an insignificant effect on inland nations. Ultimately, the findings from the long-run analysis show that regions with tropical rainforests and subtropical humid climates have a stronger capacity to adjust to climate fluctuations, whereas tropical desert zones display higher resilience to volatility in response to the change of climate.

In summary, there is considerable divergence in the works concerning the growth influences of climate variation. Empirical findings on the nexus between climate change and growth yield mixed results, with some studies indicating negative effects, others finding a positive impact, or no impact. Contemporary studies have increasingly focused on the direct growth effects of temperature variability (Kalkuhl & Wenz, 2020; Kotz et al., 2021).

## 1.2. Renewable energy consumption and economic growth

Solow (1956) and Swan (1956) identified three main factors that determine the growth of nations, encompassing accumulation of capital, labor growth, and technical advance. Solow's neoclassical model has been extended by incorporating additional determinants to capture the complexity of economic growth dynamics better. In recent years, renewable energy has been one of the most extensively discussed aspects in materials, explaining the sustainability of growth.

Alper and Oguz (2016) detected a long-term nexus between renewable energy utilization and GDP among EU members. Koçak and Şarkgüneşi (2017) showed that renewable energy usage is a key driver of GDP. A positive link between renewable energy consumption and economic growth in Portugal, with causality flowing from renewable energy used to growth between 1970 and 2010, was documented by Leitao (2010). Similarly, Bhattacharya et al. (2016) reported that long-run output elastic-

ty estimates for the 1991–2012 period show renewable energy usage exerted a significant positive influence on the economic output in 57% of the 38 leading renewable energy-consuming economies. Rafindadi and Ozturk (2017) found that a 1% rise in renewable energy usage would boost Germany's growth by 0.2194%. Saidi and Mbarek (2016) concluded that consuming renewable energy is a key component of growth. A bidirectional long-run causality had been observed between growth and renewable energy usage in China from 1977 to 2011. According to Lin and Moubarak (2014), the utilization of renewable energy stimulates growth. Analyzing the relationship among growth, renewable energy, trade, and income, Amri (2017) showed the feedback connection between the variables, meaning that they are mutually dependent. The findings also indicated that, for both developing and developed economies, renewable energy utilization drives growth. A 1% rise in renewable energy utilization would result in a 0.873% growth uptick in developed nations and a 0.678% increase in developing economies.

Estimating the influences of non-renewable and renewable energy usage on the growth of manufacturing and services, Doytch and Narayan (2021) argued that renewable energy fosters growth within high-performing sectors, specifically the services in high-income countries and manufacturing in middle-income countries. Acheampong et al. (2021) explored the causal connection among renewable energy, CO<sub>2</sub> emission, and growth across 45 sub-Saharan African economies across a 57-year time frame (1960–2017) and asserted a two-way causal association between renewable energy and growth. Several scholars have explored the feedback effect from growth to renewable energy usage. Seetharaman et al. (2019) argued that the expansion of renewable energy is primarily hindered by technological, social, and regulatory hindrances, while economic constraints do not directly affect renewable energy outcomes.

In certain cases, renewable energy usage (at threshold levels) has an insignificant influence on growth in developed economies. In some EU nations, renewable energy and economic development indicators are not correlated. Despite ongoing debates and unsteady economic environments, the share of renewable energy in overall energy

utilization across EU countries has been consistently rising and appears to be largely unaffected by economic factors (Ogonowski, 2021).

### 1.3. Trade openness and economic growth

The trade openness–growth linkage has garnered significant attention from theoretical and empirical perspectives. Theoretically, there appears to be little doubt about the long-run positive growth effect of trade openness. Most theoretical models make the assertion that trade openness facilitates growth through transfers of technology and innovation. In an economy, greater openness to trade allows economies to more readily absorb technological innovations from high-productivity trading partners, which translates into faster economic growth.

Empirically, the influence of trade opening on growth has remained a contentious topic. Many studies have shown the growth-enhancing impact of trade openness. Wacziarg and Welch (2008) found that following trade liberalization from 1950 to 1998, economies with liberalized trade policies experienced significantly higher annual growth rates, by roughly 1.5 percentage points above their pre-liberalization performances. Berg and Krueger (2003) indicated that trade significantly influences growth. Winters (2004) further supports this perspective by confirming that the growth-enhancing impact of trade openness is evident, especially over the medium-term horizon. Similarly, Brückner and Lederman (2012) also pointed out that a 1% expansion of openness accelerates short-term growth by 0.5% and long-term growth by 0.8% annually.

Besides the positive nexus narratives, the extant literature also provides evidence of a negative link between trade openness and growth. Musila and Yiheyis (2015) discovered that in Kenya, trade openness exerted a negative influence on growth. A study by Abbas (2014) on a cohort of developing and least-developed nations also highlighted the negative growth impact of trade openness. Ali and Abdullah (2015) observed that while trade openness exerts a positive short-run impact on Pakistan's growth, its long-run effect is negative, primarily due to institutional weaknesses and in-

efficient management. According to Hossain and Maitra (2020), the impacts of trade openness exhibit instability, with short-term growth-enhancing effects and long-term growth-detrimenting influences in India.

Some studies show a complex trade openness-growth nexus. Huchet-Bourdon et al. (2018) provided evidence of minimal or even negative effects of trade openness for countries with low diversification and reliance on exporting low-quality products, in contrast to more diversified economies that typically export high-quality commodities. Kim et al. (2011) also suggest that trade liberalization positively affects economies with low rates of inflation, high income, and less reliance on agriculture, while it negatively affects low-income countries experiencing high rates of inflation.

In addition, some studies have suggested that trade could support less than anticipated or negligibly to growth. Rodriguez and Rodrik (2000) showed that trade openness may enhance income without translating into sustained growth over the long term. Menyah et al. (2014) claimed an absence of growth–openness correlation in 21 examined Sub-Saharan African nations. Ayad and Belmokaddem (2017) suggested that the growth performance in the MENA region appeared largely unaffected by trade liberalization.

#### 1.4. Financial development and economic growth

Recently, financial development has emerged as a key factor driving changes in the economic advancement of nations. Financial development refers to the expansion of the scale, efficiency, and stability of financial markets, coupled with enhanced accessibility to these markets, which can offer various gains to the economy.

Economists perceive different linkages between financial development and growth. Robinson (1952) insisted that finance appears to play a limited role in driving growth; rather, it is more a result than a cause of growth. Several early studies confirmed that financial development stifles growth (Van Wijnbergen, 1983; Buffie, 1984). Lucas Jr (1988) argued that the contribution to growth of financial markets is marginal.

Numerous empirical investigations have produced inconsistent evidence regarding the financial development–growth nexus. Using the data for 77 economies in the period 1960–1989, King and Levine (1993) stressed a significant and positive nexus between financial development and real GDP per capita growth. Also, Beck and Levine (2004) contended that the bank and stock market development positively correlated with growth for 40 countries from 1976 to 1998. Leitaó (2010) identified a positive nexus between financial development and growth within 27 EU nations and 5 BRICS economies from 1980 to 2006. Likewise, Adusei (2013) found a positive link between financial development and growth, with evidence of bi-directional causality for 24 African nations from 1981 to 2010. Guru and Yadav (2019) confirmed a strong and positive correlation between financial development and growth for five emerging BRICS countries in the 1993–2014 period. However, Saci et al. (2009) showed that the stock market development positively affects growth, while the expansion of the banking sector negatively influences growth.

On the causality relationship, some studies found evidence supporting the two-way causality between financial development and growth (Luintel & Khan, 1999; Wolde-Rufael, 2009), and some found evidence of unidirectional causality, while other studies found no causation link between financial development and growth. King and Levine (1993) found that the development of finance is not a result of growth, but financial development drives growth. However, Kar and Pentecost (2000) revealed that growth fosters Turkey's financial development. Furthermore, Al-Tammam (2005) confirmed the causality connection from growth to financial development in Oman, Saudi Arabia, and Kuwait in both the short and long run. Conversely, several studies proposed the absence of causality between financial development and growth. According to Demetriades and Hussein (1996), the evidence for a causal link from financial development to growth is weak. Menyah et al. (2014) provided empirical evidence indicating that financial development does not causally influence growth. Kenza and Mohamed (2015) argued that financial development is not causally associated with growth, and the financial development role for growth is overemphasized.

To summarize, although linkages among the key variables in this study have been discussed from different angles and have significantly advanced our understanding, there is no consensus in the academic literature on the growth effects of climate change, renewable energy use, trade openness, and financial development. Consequently, this study attempts to illuminate the relationship in the context of Vietnam.

### 1.5. Gaps in existing literature

Firstly, while prior research has provided valuable insights into the growth effects of climate change, renewable energy use, trade openness, and financial development, studies examining this nexus in the countries most vulnerable to climate change are scarce. Secondly, studies that combine climate change, renewable energy usage, trade openness, financial development, and growth in one research framework are still rare. Thirdly, existing studies overlook the interplay between renewable energy usage and financial development when evaluating the growth impact of climate change and other factors.

This study aims to bridge these identified gaps by elucidating the economic growth implications of climate variation and contributing to the broader understanding of the nexus between these two factors, focusing on a single typical vulnerable country to climate change, as opposed to a set of countries. Accordingly, this study empirically examines the impact of climate change on economic growth by integrating renewable energy consumption, trade openness, and financial development within a single framework, with particular emphasis on their short- and long-run dynamics. Special attention is given to the interaction between renewable energy usage and financial devel-

opment to better capture their joint influence on growth in a climate-vulnerable economy such as Vietnam.

## 2. METHOD

### 2.1. Data and key variables

This study utilizes time series data for Vietnam from 1992 to 2022, extracted from the World Bank (WDI), FAOSTAT, and Our World in Data, to evaluate the growth impact of climate change, renewable energy usage, trade openness, and the interplay between renewable energy usage and financial development. Consistent with the literature, gross domestic product (GDP) serves as the outcome variable, while the principal explanatory variables comprise (i) gross capital formation (K), (ii) labor (L), (iii) climate change (CC), (iv) renewable energy consumption (REP), (v) trade openness (TO), (vi) interplay between renewable energy utilization and financial development (X). The variables GDP, K, and L are transformed into logarithmic form and labeled as LGDP, LK, and LL, respectively. Table 1 summarizes the variables, concise descriptions of measurements, and associated data sources.

Table 2 presents a summary of descriptive statistics, revealing central tendencies and variation across all variables of interest. The natural logarithm of GDP shows a mean of 25.69650 and a median of 25.73134, with values spanning from 24.67204 to 26.60636. Similarly, a mean of 0.733613 and a median of 0.736000 for the temperature change (CC) were observed, with values varying from 0.001000 to 1.811000. The corresponding standard deviations for these two variables are 0.578352 and 0.446576, indicating the extent of dispersion

**Table 1.** Data and variables

Variables	Label	Measurements	Data Sources
Gross domestic product	LGDP	Logarithm of GDP (constant 2015 USD)	WDI
Capital formation	LK	Logarithm of gross capital formation (constant 2015 USD)	WDI
Labor	LL	Logarithm of labor force participation	WDI
Climate change	CC	Temperature change on land	FAOSTAT
Renewable energy consumption	REP	Renewable energy consumption (% of energy consumption)	Our world in data
Trade openness	TO	The sum of exports and imports of goods and services (% of GDP)	WDI
Interplay between renewable energy consumption and financial development	X	REP * Logarithm of domestic credit to private sector (% of GDP)	WDI

**Table 2.** Descriptive statistics

Series	Mean	Median	Maximum	Minimum	Std. Dev.
LGDP	25.69650	25.73134	26.60636	24.67204	0.578352
LK	24.37846	24.64471	25.54069	22.50023	0.843100
LL	22.00927	22.02714	22.23753	21.73355	0.179270
CC	0.733613	0.736000	1.811000	0.001000	0.446576
REP	0.203888	0.200934	0.267533	0.128478	0.036416
TO	126.8932	130.7148	186.4289	66.21227	32.15245
X	0.804785	0.748515	1.294671	0.527030	0.182227

around the means. The interpretation of descriptive statistics for other variables follows a similar approach.

### 2.2. Empirical model

This study is centered on the growth impact of climate change by utilizing the ARDL bounds testing method proposed by Pesaran et al. (2001). The method applies to variables integrated of orders zero (I(0)) and one (I(1)), but not to those of integrated order higher than one.

To begin with, the stationarity test procedure, specifically the augmented Dickey-Fuller (ADF) test developed by Dickey and Fuller (1981), is implemented at both the level form and the first difference to verify that none of the variables is integrated of order two or higher.

The study adopts an econometric model based on an extended Cobb-Douglas production function to examine the growth effects of climate change, which is specified based on the standard Autoregressive Distributed Lag (ARDL) bounds testing approach:

$$\begin{aligned}
 \Delta LGDP_t = & \beta_0 + \sum_{i=1}^p \beta_{0i} \Delta LGDP_{t-i} \\
 & + \sum_{i=0}^{q_1} \beta_{1i} \Delta LK_{t-i} + \sum_{i=0}^{q_2} \beta_{2i} \Delta LL_{t-i} + \sum_{i=0}^{q_3} \beta_{3i} \Delta CC_{t-i} \\
 & + \sum_{i=0}^{q_4} \beta_{4i} \Delta REP_{t-i} + \sum_{i=0}^{q_5} \beta_{5i} \Delta TO_{t-i} + \sum_{i=0}^{q_6} \beta_{6i} \Delta X_{t-i} \\
 & + \theta_0 LGDP_{t-1} + \theta_1 LK_{t-1} + \theta_2 LL_{t-1} + \theta_3 CC_{t-1} \\
 & + \theta_4 REP_{t-1} + \theta_5 TO_{t-1} + \theta_6 X_{t-1} + u_t,
 \end{aligned} \tag{1}$$

where the variable  $X = REP \cdot LFD$  describes the interplay between renewable energy utilization and financial development,  $\Delta$  demonstrates the first difference notation;  $\beta_0$  represents the constant;  $\theta_i$  ( $i = 0..6$ ) and  $\beta_{kj}$  ( $k = 0..6$ ) illustrate the long- and short-run effects, respectively;  $u_t$  denotes the error term at time  $t$ ;  $q_i$  ( $i = 1..6$ ) exhibit the lag lengths assigned for the corresponding short-run variable.

In the second step, the Akaike information criterion (AIC) is adopted to identify the proper lag structure in the specified first-differenced model to choose the best one with the lowest value of AIC. The ARDL bounds testing procedure employs an  $F$ -statistic that checks the joint significance of lagged regressors on the dependent variable to verify the cointegration presence hypothesis:

$$H_0 : \theta_1 = \theta_2 = \theta_3 = \theta_4 = \theta_5 = \theta_6 = 0, \tag{2}$$

$$H_A : \theta_1 \neq \theta_2 \neq \theta_3 \neq \theta_4 \neq \theta_5 \neq \theta_6 \neq 0. \tag{3}$$

Subsequently, to determine the existence of cointegration, Pesaran et al. (2001) and Narayan (2004) introduced asymptotic lower and upper critical bounds – corresponding to I(0) and I(1), respectively. If the computed  $F$ -statistic value is lower than the lower bound,  $H_0$  is retained, indicating the absence of cointegration. If it exceeds the upper bound, cointegration is present. When the  $F$ -statistic locates between the two critical bounds, no definitive inference regarding cointegration can be made.

If cointegration is present, the next step involves estimating the error correction model (ECM) to assess the short-run dynamics:

$$\begin{aligned} \Delta LGDP_t = & \beta_0 + \sum_{i=1}^p \beta_{0i} \Delta LGDP_{t-i} \\ & + \sum_{i=0}^{q_1} \beta_{1i} \Delta LK_{t-i} + \sum_{i=0}^{q_2} \beta_{2i} \Delta LL_{t-i} + \sum_{i=0}^{q_3} \beta_{3i} \Delta CC_{t-i} \\ & + \sum_{i=0}^{q_4} \beta_{4i} \Delta REP_{t-i} + \sum_{i=0}^{q_5} \beta_{5i} \Delta TO_{t-i} + \sum_{i=0}^{q_6} \beta_{6i} \Delta X_{t-i} \\ & + \mu ECT_{t-1} + u_t, \end{aligned} \tag{4}$$

where *ECT* denotes the error correction term, and  $\mu$  reflects the adjustment speed. The estimated value of  $\mu$  is anticipated to be within the range of -1 to 0, and statistically significant. The ARDL approach is immensely beneficial as it enables the simultaneous estimation of both short-run and long-run effects of explanatory factors on the target variable.

Thereafter, to verify that the estimated parameters of the ARDL model in this study adhere to the assumptions of the standard linear regression framework, diagnostic and stability tests are conducted. This study utilizes the Ramsey RESET test to assess potential model misspecification, the Jarque-Bera statistic for residual normality, the Breusch-Godfrey Lagrange multiplier test to detect serial correlation, White’s test to examine the presence of heteroscedasticity, and the cumulative sum (CUSUM) and cumulative sum of squares (CUSUMSQ) tests for model stability. Finally, the study conducts pairwise Granger causality testing on the causality direction.

### 3. RESULTS AND DISCUSSION

#### 3.1. Unit root test results

The ADF test is conducted on the series LGDP, LK, LL, CC, REP, TO, and X at the level and the first difference to check the stationarity. The test is car-

ried out with an intercept. The hypothesis  $H_0$  of stationarity is dropped if the *p*-value exceeds 5%. The ADF test results represented in Table 3 confirm the stationarity of the series LK at level, indicating that LK is I(0), while LGDP, LL, CC, REP, TO, and X are non-stationary at level but become stationary after first differencing, implying that they are I(1). Since all series are either I(0) or I(1), employing the ARDL framework is suitable.

#### 3.2. Model selection

Following the stationarity test, the subsequent step is to select the suitable ARDL model. The ARDL bounds test for examining the cointegration among the series requires selecting the model with the optimal lag structure, assuming the absence of serial correlation in the residuals. One of the criteria for choosing the ARDL model with best-fitting lag is AIC. The lag lengths are optimal if the AIC value is minimized and the model has no autocorrelation in the error terms. Figure 1 presents the top 20 ARDL models. The most stable model is ARDL (1, 1, 3, 3, 1, 2, 2) with the lowest AIC value.

#### 3.3. Co-integration test results

The *F*-statistic outcome and the critical bounds shown in Table 4 indicate that the computed *F*-statistic lies above the I(1) bound under all standard levels of statistical significance. This provides sufficient evidence for the rejection of the null hypothesis and the acceptance of the opposing hypothesis. Accordingly, the presence of a stable long-run equilibrium linkage among the variables is confirmed.

#### 3.4. Long-run estimation results

The evidence on the long-run connection between LGDP and explanatory factors (LK, LL, CC, REP,

**Table 3.** Unit root test

Variables	Level		1 <sup>st</sup> Difference		Outcome
	t-Statistic	Prob.	t-Statistic	Prob.	
LGDP	-1.950281	0.3058	-4.522598	0.0013	I(1)
LK	-4.483186	0.0013	-	-	I(0)
LL	-1.411217	0.5635	-3.585462	0.0125	I(1)
CC	-0.590006	0.8571	-6.393604	0.0000	I(1)
REP	-2.381847	0.1551	-4.840398	0.0006	I(1)
TO	-0.619590	0.8517	-5.517342	0.0001	I(1)
X	-1.321938	0.6062	-5.210403	0.0002	I(1)

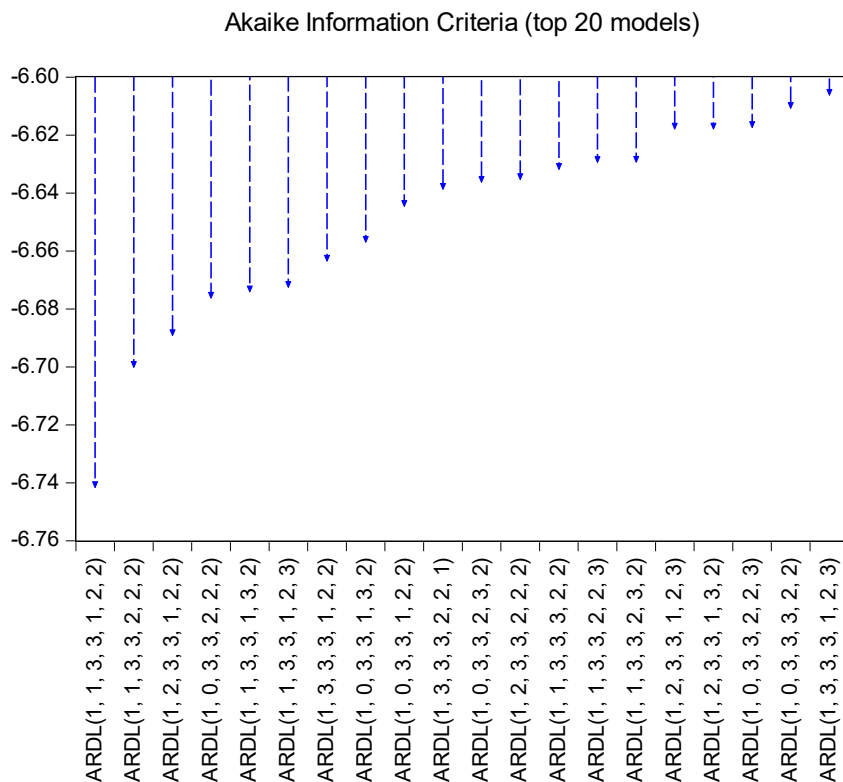


Figure 1. AIC levels

Table 4. ARDL bound test results

Number of regressors	Test statistic	Critical value bounds							
		90%		95%		97.5%		99%	
k	F-statistic	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
6	38.73905	1.99	2.94	2.27	3.28	2.55	3.61	2.88	3.99

TO, and X) is presented in Table 5. The outcomes suggest that explanatory variables are significant in accounting for economic growth. Capital formation is a crucial determinant of production. Vietnam has been attracting a growing amount of both domestic and foreign investment. This includes new enterprises, business expansion, and infrastructure upgrades. The country is expanding its financial markets, facilitating easier financing access for businesses to thrive. It contributes to the expansion of the economic scale and plays a noteworthy role in Vietnam’s growth.

The regression coefficient of 0.175 of CC confirms that climate variability has a positive and statistically significant impact on growth in Vietnam. A 1-degree Celsius increase in temperature correlates with approximately a 0.18% GDP improvement in the long term. The implications of climate change

can stimulate technological progress in key sectors such as renewable energy, enhanced energy efficiency, and adaptation measures to mitigate its impacts. The necessity to address the challenges presented by climate variability stimulates R&D, resulting in innovations in sustainable agricultural practices, renewable energy technologies, and infrastructure resilient to climate change impacts. The positive effect of rising temperatures can also be attributed to the growth of certain industries in warmer conditions. Ascending summer temperatures positively affect certain industries, including the production of refrigerators and air conditioners, the solar industry, and mining, all of which could gain from rising energy consumption during blazing days. Climate change poses challenges that may motivate innovation and adaptation within the economy, leading to the invention of new techniques, technologies, and real measures

that bolster the ability to cope with change. In some regions of Vietnam, agricultural yields may be higher due to climate change. The estimated result reveals that strategies to adapt and minimize the detrimental growth impact of climate variability are appropriate and effective. The result is reinforced by the study implemented on Pakistan's economy by Khurshid et al. (2022), who stressed that a one-unit rise in temperature contributes to a 0.0566% increase in growth. The result also aligns with Zhao and Liu's (2023) finding on the significant contribution of temperature variations to growth in coastal countries. Nonetheless, this result warrants cautious interpretation. Even if the initial economic impact may be positive, this does not mean that temperature changes will continue to exert a favorable influence on economic growth over time. The medium-term economic benefits of climate change could begin to decline at any point going forward. The finding is contrary to Dell et al. (2012), Abidoye and Odusola (2015), and Souvannasouk et al. (2021).

As anticipated, using renewable energy sources has a positive effect on Vietnam's growth. The REP coefficient of 1.115 is statistically significant at 10%, meaning a 1% expansion of renewable energy in the energy consumption structure leads to 1.1% growth in GDP. The outcome underscores the role of renewable energy utilization in improving the long-run growth rate. Accordingly, a transition from fossil fuels to renewable energy sources has a significant positive impact on economic growth and, by extension, sustainable development. The findings indicate that the energy policies of Vietnam targeting sustainable growth have likely been effective in the long run. Vietnam can reap numerous economic benefits from expanding renewable energy use, encompassing enhanced energy security and autonomy, technological innovation, cost reduction and economic efficiency rise, employment generation, environmental sustainability ascent, rural advancement, attracting foreign investment, and green finance

development. This outcome is congruent with prior findings of Rafindadi and Ozturk (2017) and Amri (2017).

Directing attention to trade openness, the TO coefficient is negative and statistically significant at the 5% threshold. The result implies that a 1% improvement in trade openness leads to the shrinking in GDP on 0.004%. Vietnam's openness to international trade plays an unconstructive role in Vietnam's long-term growth performance. This is attributed to the country's continued heavy reliance on imports, with most of its exports being composed of raw or primary goods and low-value-added commodities. This could be explained by the low positioning of the country in the overall production value chains. Besides, a shortage of a highly skilled workforce, slow institutional reform, and a sluggishly improving business environment also present significant obstacles to attaining desired growth via trade. Expectations that trade openness can bring benefits in terms of growth, productivity improvement, and technology transfer may not have been achieved. Hence, there is a big gap between the expected benefits from trade openness and the actual growth impact of trade. Thus, Vietnam needs to be cautious when adopting an open-trade policy with a high level of openness. The result is consistent with Abbas (2014) and Musila and Yiheyis (2015) on the adverse growth impact of trade openness. However, it contradicts the findings of Wacziarg and Welch (2008), Winters (2004), and Brückner and Lederman (2012) on the significantly favorable linkage between openness and growth.

The impact of X representing the interplay between renewable energy utilization and financial development negatively affects the long-run growth. Still, the estimated coefficient is statistically insignificant at typical thresholds. The outcome points to the fact that financial development may curb the positive impact of renewable energy usage on growth. This shows that a more effective

**Table 5.** Long-run model estimates

Variable	LK	LL	CC	REP	TO	X	C
Coefficient	0.885***	-0.287	0.175***	1.115*	-0.004**	-0.026	10.641**
p-value	(0.0001)	(0.3582)	(0.0052)	(0.0964)	(0.0127)	(0.8530)	(0.0231)

Note: \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.1$ . Dependent Variable: LGDP.

strategy is necessary for Vietnam to link financial development with renewable energy to promote sustainable growth.

### 3.5. Short-run estimation results

Table 6 displays the outcomes of the estimated ECM. The estimated parameter for the lagged ECT coefficient is negative (−0.570429) and statistically significant at the threshold of 1%. This reaffirms a cointegrated relationship presence among the model’s variables. The finding indicates that any aberration from the equilibrium in the short-term between explanatory variables and LGDP after the exogenous shock is adjusted toward the equilibrium in the long term with a yearly adjustment speed of 57%. Put differently, the estimated ECT coefficient implies that over 57% of the disequilibrium from the prior year will be adjusted within the current year. The outcome reveals a medium adjustment pace toward long-run equilibrium following short-run shocks.

$$ECT = LGDP - (0.885 \cdot LK - 0.287 \cdot LL + 0.175 \cdot CC + 1.116 \cdot REP - 0.004 \cdot TO - 0.026 \cdot X + 10.641). \quad (5)$$

The short-term estimation results indicate that fluctuations in temperature change and the inter-

play between renewable energy usage and financial development facilitate growth, whereas variations in the consumption of renewable energy and trade openness undermine growth. In addition, the previous change of temperature adjustment and interplay between renewable energy usage and financial development have adverse effects on growth at 1% significance level.

### 3.6. Diagnostic tests

Table 7 summarizes the diagnostic test outcomes. The computed probability values exceed the 10% threshold, indicating the absence of serial correlation and heteroskedasticity, confirming residual normality, and supporting correct model specification.

Within the ARDL approach, CUSUM and CUSUMSQ tests were applied to assess the parameter stability. The outcomes shown in Figures 2a and 2b imply that coefficients are stable for the ECM model as the CUSUM and CUSUMSQ lines fall within the critical bands of 5% confidence intervals.

### 3.7. Granger causality test results

According to the pairwise Granger causality test outcomes displayed in Table 8, LGDP Granger causes CC at the 1% significance level, and CC

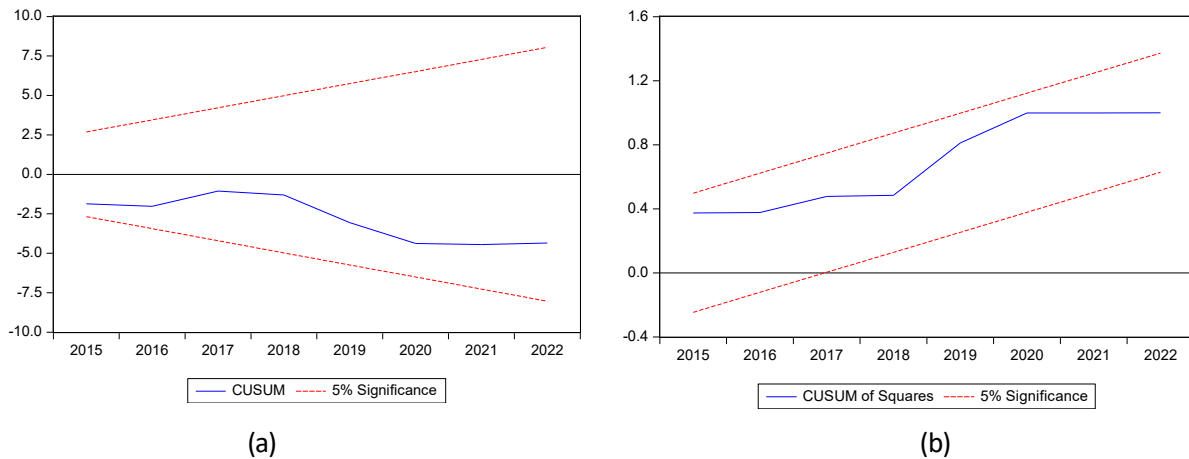
**Table 6.** Short-run model estimates

Variable	Coefficient	p-value	Variable	Coefficient	p-value
D(LK)	0.399159***	0.0000	D(REP)	−0.561594*	0.0603
D(LL)	0.047078	0.5336	D(TO)	−0.000505**	0.0148
D(LL(−1))	0.197479**	0.0309	D(TO(−1))	0.000573***	0.0073
D(LL(−2))	−0.582652***	0.0001	D(X)	0.152701**	0.0285
D(CC)	0.018177**	0.0014	D(X(−1))	−0.092056***	0.0000
D(CC(−1))	−0.069091*	0.0000	ECT(−1)	−0.570419***	0.0000
D(CC(−2))	−0.026861**	0.0001	–	–	–

Note: \*\*\* p < 0.01, \*\* p < 0.05, \* p < 0.1. Dependent variable D(LGDP).

**Table 7.** Results of diagnostic tests

Types of Test	Diagnostic Test	Test Statistic	Prob.
Functional form	Ramsey RESET test	F(1, 7) = 0.71018	0.4272
Serial correlation	Breusch-Godfrey Serial correlation LM test	F(2, 6) = 3.162202	0.1154
Heteroskedasticity	Breusch-Pagan-Godfrey test	F(19, 8) = 0.870494	0.6225
Normality	Jarque-Bera	JB = 2.348019	0.3091



**Figure 2.** The plot of the cumulative sum of recursive residuals (a) and the plot of the cumulative sum of squares of recursive residuals (b)

**Table 8.** Granger causality test

Null Hypothesis	F-statistic	p-value
CC does not Granger Cause LGDP	1.11241	0.3451
LGDP does not Granger Cause CC	5.85259	0.0085
REP does not Granger Cause LGDP	3.31988	0.0533
LGDP does not Granger Cause REP	0.70309	0.5050
TO does not Granger Cause LGDP	0.98901	0.3866
LGDP does not Granger Cause TO	2.02953	0.1533
X does not Granger Cause LGDP	5.23393	0.0130
LGDP does not Granger Cause X	6.56837	0.0053

does not Granger cause LGDP, indicating a one-way causality flowing from growth to climate change. Similarly, there is a causality that runs from renewable energy usage to growth. In addition,

the findings also show a significant two-way Granger causality between growth and the interplay between renewable energy utilization and financial development for Vietnam.

## CONCLUSION

This study aims to clarify the growth influence of climate change, taking into account the roles of renewable energy consumption, trade openness, and the interplay between renewable energy utilization and financial development. Using the ARDL approach and annual data for Vietnam from 1992 to 2022, the empirical results reveal several noteworthy findings. Effective impact mitigation and adaptation measures to climate variability have the potential to enhance Vietnam's long-term growth prospects. On the other hand, estimates also detect the negative growth impact of trade openness. In the short run, variations in temperature change and the interplay of renewable energy usage and financial development contribute to growth, while changes in renewable energy consumption and trade openness restrain growth. Empirical evidence indicates the presence of a one-way causality flowing from economic growth to climate change, and from renewable energy usage to growth. In addition, the results confirm a bidirectional Granger causality between growth and the interplay of renewable energy utilization and financial development in the Vietnamese context.

Drawing from the findings, the following policy implications are suggested. First, formulating and implementing effective climate change adaptation and mitigation strategies should be a top priority for policymakers. Second, the transformation of the energy use structure toward more renewable energy

serves as a critical driver of economic growth. The government needs to create favorable conditions for optimizing the energy sector structure and directing investment capital toward green and environmentally friendly industries to transform the industrial structure toward a more sustainable and low-carbon direction. The government should also prioritize long-term investments in renewable energy R&D to accelerate the ongoing advancement of new technologies and equipment, thereby creating a conducive environment for the renewable energy sector's growth. Third, Vietnam should adopt policies that ensure productive engagement with international trade to boost its growth. While the importance of trade in a growingly globalized world is recognized, it is also worth noting that trading activities detrimental to domestic growth should not be supported. We therefore recommend focusing investment on strengthening domestic value chains to reduce reliance on low value-added exports.

The study's findings are constrained by the fact that it utilizes only temperature variability to represent climate change. This leaves room for future research, especially incorporating other factors representing climate change into the analysis as data become available. Moreover, the potential non-linear relationship between temperature variations and growth remains unexamined in the present study.

## AUTHOR CONTRIBUTIONS

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Funding acquisition: Vu Phuong Anh Do.

Investigation: Quoc Hoi Le.

Methodology: Vu Phuong Anh Do, Thi Cam Van Nguyen, Quoc Hoi Le.

Resources: Quoc Hoi Le.

Software: Vu Phuong Anh Do, Thi Cam Van Nguyen.

Supervision: Quoc Hoi Le.

Writing – original draft: Thi Cam Van Nguyen.

Writing – review & editing: Thi Cam Van Nguyen, Quoc Hoi Le.

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