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Vietnam's Development Trajectory: Threshold Cointegration and Causality Analysis of Energy Consumption and Economic Growth

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Abstract

This study examines the relationship between per capita energy consumption and per capita GDP in Vietnam from 1976 to 2008 using threshold cointegration analysis. The findings confirm a long-term cointegration relationship between the variables, with a significant structural breakpoint in 1992, indicating a shift in the energy-growth dynamics. The results support the neoclassical view that energy consumption does not constrain economic growth, suggesting that Vietnam can implement energy conservation policies without negatively impacting its economy. The presence of a time-varying effect highlights the evolving nature of the energy-growth relationship, emphasizing the need for adaptive policy measures. A key policy implication is that the government can pursue environmentally sustainable energy-saving policies while maintaining economic expansion. The study recommends allocating energy resources efficiently to maximize productivity across various sectors. Given Vietnam's economic growth trajectory, focusing on renewable energy sources and enhancing energy efficiency can contribute to long-term sustainability. The findings provide empirical evidence for policymakers to design strategic energy policies that balance economic growth with environmental concerns. By integrating conservation strategies with economic planning, Vietnam can ensure sustainable development while reducing energy dependency. The study adds to the ongoing debate on energy-growth linkages, offering valuable insights for emerging economies seeking to optimize energy use without compromising growth. The government should prioritize investment in energy-efficient technologies and promote sustainable energy practices to enhance economic resilience and environmental sustainability.

Keywords: Energy consumption, Economic growth

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1. INTRODUCTION

The heightened volatility of energy prices and the escalating greenhouse gas emissions have become focal points for both academics and policy-makers in the formulation of energy conservation policies. However, the implementation of such policies cannot be arbitrary; it necessitates a thorough examination of the causal relationship between energy consumption and economic growth. In specific contexts, policy-makers must discern whether economic growth stimulates energy consumption or if, conversely, energy consumption drives economic growth. This matter remains a subject of ongoing debate among energy economists, lacking a consensus. The exploration of the causal link between energy consumption and economic growth has been a subject of extensive investigation since the seminal work of Kraft and Kraft (1978).

The principal rationale for the neutral impact of energy on economic growth lies in the insignificance of energy costs, making it unlikely to exert a substantial influence on overall economic growth. Additionally, it has been posited that the potential impact of energy consumption on growth is contingent upon the economic structure and the level of economic development in the respective country. As economies progress, there is a tendency for their production structure to transition towards service sectors, which typically exhibit lower dependence on energy inputs (Solow, 1974; Cheng, 1995; Okurut & Mbulawa, 2018). Moreover, the negligible impact of energy costs on economic growth suggests that alternative factors, such as technological advancements or institutional frameworks, may play a more pivotal role in shaping the trajectory of economic development. It is essential to recognize that the dynamics between energy consumption and economic growth are intricate and multifaceted, necessitating a nuanced understanding of the interplay between these variables. Future research endeavors should delve deeper into the contextual variations across economies to unravel the diverse implications of energy consumption on economic growth. Furthermore, the identification of uni-directional causality from economic growth to energy consumption aligns with the 'conservation hypothesis.' This signifies that a country can implement energy conservation policies without detrimental effects on economic growth. Additionally, the observation of uni-directional causality from energy consumption to economic growth, commonly associated with the 'energy-led growth hypothesis,' emphasizes the pivotal role of energy as a critical input in production. Proponents of this hypothesis assert that energy functions as a complement to fundamental factors such as land, labor, and capital, making it a potential limiting factor for economic growth (Stern, 1993; Cleveland et al., 2000; Ahmad, 2018; Marc & Ali, 2018). As such, policymakers need to carefully consider and address constraints on energy use to mitigate potential impediments to economic growth within this framework. Conclusively, the identification of bi-directional causality between energy consumption and economic growth is encapsulated by the 'feedback hypothesis.' This perspective illuminates that energy consumption and economic growth are intricately interlinked, mutually influencing and shaping each other. The acknowledgment of this feedback mechanism underscores the need for a comprehensive and integrated approach in policymaking, recognizing the reciprocal relationship between energy utilization and economic development.

Chen et al. (2007) assert that the divergent findings in previous studies stem not only from variations in datasets and econometric methodologies but also from the unique characteristics of different countries. Consequently, formulating future energy policies for a particular country based on the experiences of others is deemed precarious (Marc & ali, 2016; Iqbal, 2018). To ensure the efficacy of energy policy design, it becomes imperative to undertake a country-specific causality study, shedding light on the intricate relationship between energy consumption and economic growth. While numerous causality studies have been conducted globally, a notable gap exists in the examination of this relationship for Vietnam. Therefore, there is an urgent need to scrutinize and elucidate the causal dynamics between energy consumption and economic growth within the Vietnamese context.

2. LITERATURE REVIEW

The exploration of the relationship between energy consumption and economic growth has been theoretically examined through two primary approaches. Within the neoclassical growth models, energy is essentially regarded as an intermediate input in the production process. This conceptualization is grounded in the potential for technological advancements and the substitution of alternative physical inputs for energy, aiming to utilize existing energy resources more efficiently. Furthermore, it seeks to foster the generation of renewable energy resources, mitigating the impact of binding supply constraints (Solow, 1974, 1997; Stiglitz, 1997). In

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accordance with this perspective, energy is positioned as one among the non-essential inputs in the production process. Advocates of this theory lend support to the 'neutrality hypothesis' and 'conservation hypothesis.' Essentially, these hypotheses posit that constraints on energy supply may not yield detrimental effects on economic growth. This perspective underscores the belief that alterations in energy availability might not significantly impact overall economic growth, aligning with the principle of energy's neutrality within the production process (Muhieddine, 2018; Ali & Audi, 2016). Conversely, the ecological economic theory posits that energy consumption serves as a constraining factor on economic growth, particularly in contemporary economies. Advocates of ecological economics contend that technological advancements and alternative physical inputs cannot effectively substitute for the essential role played by energy in the production process (Stern, 1993, 2000). This perspective challenges the notion of substitutability and emphasizes the indispensable nature of energy in driving economic production within modern economies. In this paradigm, proponents go so far as to designate energy as the primary source of value, asserting that other factors of production, such as labor and capital, are rendered ineffective without the indispensable contribution of energy. This perspective underscores the foundational role that energy plays in facilitating and enabling the functionality of essential production factors within the economic system.

Numerous empirical studies exploring the nexus between energy consumption and economic growth, utilizing diverse datasets from various countries, have yielded varied and sometimes contradictory results. The concept of causality between energy consumption and economic growth was initially introduced in the seminal work of Kraft and Kraft (1978). They applied a standard version of the Granger causality test (standard Granger) and found evidence supporting a unidirectional long-run relationship, running from gross domestic product to energy consumption for the USA during the 1947-74 period. This study implies that governments could potentially pursue energy conservation policies based on the identified causality. Contrastingly, employing the Sims causality technique, Akarca and Long (1980) presented findings that revealed no evidence of causality between energy consumption and GDP. They critically scrutinized the results obtained by Kraft and Kraft, attributing their findings to temporal sample instability. Subsequently, numerous academics have actively engaged in the debate, yet a consensus remains elusive, underscoring the ongoing and intricate nature of the discourse on the causal relationship between energy consumption and GDP. Similarly, Yu and Hwang (1984) adopted the Sims causality test with annual data, revealing no causality between energy consumption and GDP in the USA during the 1947-79 period. However, when employing quarterly data and the same testing method, the authors found a unidirectional causality running from gross national product to energy consumption in the USA for the 1973-81 period. This discrepancy highlights the sensitivity of the results to the chosen temporal granularity and adds another layer of complexity to the ongoing discourse on energy consumption and economic growth causality.

Yu and Choi (1985) utilized the standard Granger causality test over the 1954-1976 period to investigate the causal linkages between gross national product and various types of energy consumption across multiple countries. Their empirical findings revealed a unidirectional causality running from economic growth to energy consumption for Korea, another unidirectional causality running from energy consumption to income for the Philippines, while no discernible causality existed in the USA, Poland, and the UK. This diversity in causality patterns underscores the importance of considering country-specific dynamics in understanding the energy consumption and economic growth relationship. Erol and Yu (1987) conducted comprehensive analyses using both Sims and Granger causality tests. Their results indicated unidirectional causality from energy consumption to income for West Germany, bi-directional causality for Italy, and no evidence of causality for the UK, Canada, and France. Moreover, the study by Erol and Yu (1987) highlighted a unidirectional causality from energy consumption to economic growth for Japan over the 1950-1982 period. However, it is noteworthy that this causal relationship lost significance when the sample was confined to the 1950-1973 period. These results underscore the importance of considering specific time frames when analyzing the dynamic interplay between energy consumption and economic growth, indicating the intricate nature of their relationship over different periods. In their study, Hwang and Gum (1992) employed cointegration and error correction models, revealing a bi-directional causal relationship between energy consumption and economic growth in Taiwan over the period 1955-1993. This finding suggests a dynamic interaction where changes in energy consumption and economic growth mutually influence each other, emphasizing the need to consider such bidirectional causality in formulating energy and economic policies. Through the application of cointegration and the error-correction version of Granger causality test (ECM), Cheng (1995) identified the existence of a uni-directional causality running from economic growth to energy consumption in India. This insight underscores the importance of understanding the causal links between economic development and energy use to formulate effective policies in the context of India's specific conditions.

Masih and Masih (1996, 1997) conducted an in-depth exploration into the relationship between energy and GDP in multiple Asian countries. Their findings revealed cointegration between energy and GDP in India, Pakistan, and Indonesia, while non-cointegration was observed in Malaysia, Singapore, and the Philippines. The application of the vector error correction model with the same dataset uncovered various causal patterns. Notably, a uni-directional causality was identified from energy consumption to income in India, a uni-directional causality from economic growth to energy consumption in Indonesia, and bi-directional causality in Pakistan. For the non-cointegrated countries, including Malaysia, Singapore, and the Philippines, the standard Granger causality test did not reveal any significant causality. These results underscore the importance of country-specific analyses to capture the nuanced dynamics between energy consumption and economic variables. Glasure and Lee (1997) conducted a comprehensive examination of the causality between energy consumption and GDP in South Korea and Singapore, employing various methodologies. The results from standard Granger causality tests indicated no causal relationship for South Korea. In contrast, a uni-directional causal relationship running from energy consumption to GDP was identified for Singapore. However, the application of the error correction model signaled bi-directional causality for both countries. These divergent outcomes highlight the sensitivity of causality assessments to the chosen analytical approach and emphasize the need for a nuanced understanding of the relationship between energy consumption and economic variables across different contexts. Cheng and Lai (1997) utilized Hsiao's version of Granger causality to explore the relationship between energy consumption and GDP in Taiwan over the period 1955–1993. Their study revealed a unidirectional causality running from GDP to energy consumption without feedback in Taiwan. This finding underscores the importance of considering temporal dynamics in understanding the causal linkages between energy consumption and economic variables, with implications for policy considerations in Taiwan's context. Yang (2000) conducted a re-examination of the causality between energy consumption and GDP in Taiwan, utilizing updated data for the period 1954–1997. This study contributes to the ongoing exploration of the dynamic relationship between energy use and economic growth in Taiwan, considering the evolving patterns over the extended timeframe. The findings of this paper contradict the results reported by Cheng and Lai (1997), who identified unidirectional causality

from GDP to energy consumption for Taiwan. Instead, Yang (2000) presents evidence supporting the existence of a bi-directional causality between energy consumption and GDP in Taiwan. This discrepancy underscores the complexity of the relationship between economic growth and energy use, emphasizing the importance of considering various factors and methodologies in analyzing causation patterns.
Asafu-Adjaye (2000) conducted a comprehensive analysis of the causal relationship between energy use and income in four Asian countries, namely India, Indonesia, Thailand, and the Philippines, employing Error Correction Models. The outcomes of the tests revealed a uni-directional causality from energy to income in India and Indonesia, while Thailand and the Philippines exhibited a bi-directional causality. This study contributes to the nuanced understanding of the intricate dynamics between energy consumption and income across diverse Asian economies. Aqeel and Butt (2001) delved into the causal dynamics between energy consumption, economic growth, and employment in Pakistan using Error Correction Models. The findings suggested a unidirectional causality, indicating that economic growth had a causal effect on total energy consumption. This research contributes valuable insights into the specific causal linkages within the context of Pakistan's energy and economic landscape. Soytas and Sari (2003) conducted an extensive analysis on the causality between energy consumption and GDP, focusing on both G7 countries and the top 10 emerging economies. Their study uncovered diverse causal relationships, including bi-directional causality for Argentina, uni-directional causality from GDP to energy consumption in Italy and Korea, and uni-directional causality from energy consumption to GDP in Turkey, France, Germany, and Japan. These nuanced findings underscore the varied nature of energy-economic dynamics across different countries and provide valuable insights for policymakers and researchers alike.
In a comprehensive reassessment of the causality between energy consumption and economic growth in India, Paul and Bhattacharya (2004) utilized the ECM model for the period spanning 1950–1996. Their study revealed a bi-directional causality between energy consumption and economic growth. Furthermore, employing the Johansen cointegration testing approach, they consistently identified the same direction of causality between energy consumption and economic growth. These findings contribute valuable insights into the intricate dynamics of energy and economic interactions, particularly in the context of India's evolving landscape. Altinaya and Karagol (2004) conducted a meticulous analysis of the causal relationship between GDP and energy consumption in Turkey, employing Hsiao’s version of Granger causality over the period 1950–2000, which accounted for structural breaks. Their primary conclusion, drawn from the examination of detrended series, suggests a lack of evidence supporting causality between energy consumption and GDP in Turkey. This nuanced understanding adds valuable insights to the intricate dynamics of energy and economic interactions within the Turkish context during the specified period.
In a comprehensive exploration, Lee (2005) delved into the intricacies of cointegration and the causal relationship between energy consumption and GDP across 18 developing countries. Analyzing data spanning the years 1975–2001 and employing a robust methodological framework including panel unit root tests, heterogeneous panel cointegration, and panel ECM models, Lee's study revealed compelling empirical evidence supporting a long-run cointegration relationship between energy consumption and GDP, accounting for the heterogeneity in country effects. Significantly, the findings pointed towards both long-run and short-run causalities originating from energy consumption to GDP. This outcome underscored the potential adverse impact of energy conservation policies on economic growth in the context of developing countries, offering valuable insights for policymaker. Wolde-Rufael (2005) conducted a comprehensive study employing cointegration and a modified version of the Granger causality test to scrutinize the long-run and causal dynamics between per capita GDP and per capita energy use across 19 African countries during the period 1971–2001. The findings of the study strengthened the case for a long-run relationship in eight out of the nineteen countries, with causality being observed in twelve out of nineteen countries. This nuanced analysis contributed valuable insights into the intricate economic and energy dynamics within the African context.
Mehrara (2007) delved into the intricate relationship between per capita energy consumption and per capita GDP across a group of eleven oil-exporting countries, which included Iran, Kuwait, Saudi Arabia, United Arab Emirates, Bahrain, Oman, Algeria, Nigeria, Mexico, Venezuela, and Ecuador. Employing panel unit root tests and panel cointegration tests, the study revealed a uni-directional causality, indicating that economic growth influences energy consumption in these oil-exporting nations. Significantly, the results advocated for energy conservation policies, emphasizing the potential of reforming energy prices without detrimental effects on economic growth. This insight holds relevance for countries heavily reliant on oil exports. Chiou-Wei et al. (2008) undertook a comprehensive investigation, employing both linear and nonlinear Granger causality tests, to scrutinize the intricate relationship between energy consumption and economic growth. Their study encompassed a panel of Asian newly industrialized countries along with the USA, spanning the years 1954 to 2006. The findings reinforced the neutrality hypothesis for the USA, Thailand, and South Korea. Intriguingly, a uni-directional causality emerged, indicating that economic growth influences energy consumption in the Philippines and Singapore. Conversely, potential negative effects of energy consumption on economic growth were discerned for Taiwan, Hong Kong, Malaysia, and Indonesia, shedding light on the nuanced dynamics across different economies in the region. Chontanawat et al. (2008) conducted a thorough examination of causality between energy and GDP, utilizing a comprehensive dataset and Granger tests across thirty OECD countries and seventy non-OECD countries. Their findings indicated a more prevalent causality running from energy to GDP in the developed OECD countries, showcasing distinct patterns in the relationship between energy consumption and economic growth across different economic contexts.

3. DATA AND METHODOLOGY

This study utilizes time series data spanning from 1976 to 2008, focusing on per capita GDP and per capita energy consumption in Vietnam. Per capita energy consumption is measured in kilograms of oil equivalent, while per capita GDP is expressed in constant 2000 US dollars. The chosen starting period takes into consideration the availability of data and significant historical events, notably the end of the Vietnam War in 1975 and the country's unification in 1976. It is important to note that all variables are transformed into natural logarithms to mitigate heteroskedasticity, and the growth rate is obtained by differencing the logarithms of the relevant variables. There appears to be a potential structural break in the series around the year 1991. Conducting the Quandt-Andrews breakpoint test reveals breakpoints for per capita GDP at the year 1992 and for per capita energy consumption at the year 1993. Figure 2 and 3 visually depict these breakpoints. The observed breakpoints suggest the possibility of PC causing PC, although a definitive conclusion requires further validation through Granger causality tests, as presented in the empirical results. Additionally, both series exhibit an upward growth trend since these breakpoints, as illustrated in the figures. To determine the order of integration of the variables, this study initially utilizes conventional unit root tests, namely the augmented Dickey-Fuller and Phillips-Perron

tests. In general, a variable is considered integrated of order d, denoted as I(d), if it becomes stationary after differencing d times. A variable is regarded as integrated of order greater than or equal to 1 if it remains non-stationary after differencing. The unit root tests help assess the stationarity properties of the variables under consideration. As highlighted by Asteriou and Hall (2007), a common observation is that many economic variables exhibit cointegration of order 1. Cointegration implies a long-term relationship among variables, and of order 1 suggests that the variables share a common stochastic trend. Perron (1989) has demonstrated that a Dickey and Fuller (1979) type test for a unit root may lack consistency when the alternative hypothesis involves a stationary noise component with a break in the slope of the deterministic trend. His key insight is that the presence of an exogenous shock with a permanent effect can result in a failure to reject the unit root hypothesis, even when it is false. This underscores the importance of accounting for structural breaks in unit root tests to obtain accurate assessments of the stationarity of time series data.
In response to the limitations of conventional unit root tests, Perron (1989) introduced a unit root test that accommodates structural breaks, presenting three alternative models: the crash model (involving a shift in the intercept), the changing growth model (entailing a change in the slope), and the model involving changes in both the intercept and the slope. Numerous studies have revealed instances where traditional unit root tests, which assume stationarity, fail to reject the unit root hypothesis for series that are, in fact, trend-stationary with a structural break. Perron's approach allows for a more robust assessment of stationarity by considering the possibility of structural breaks in the data. However, critics have raised concerns about the Perron (1989) test, primarily for its assumption that the time of the break is exogenous, meaning it is known a priori. Scholars such as Christiano (1992) and Altinay and Karagol (2004) have questioned this aspect of the test methodology. Zivot and Andrews (1992) made advancements in the Perron unit root tests by treating the breakpoint (τb) as an endogenous parameter. This innovation aimed to address some of the concerns associated with exogenous breakpoint assumptions in previous tests.
After determining the order of integration for each variable, the study proceeds to assess whether the variables are cointegrated. Engle and Granger (1987) posit that a linear combination of two or more nonstationary series, with the same order of integration, may yield a stationary outcome. The identification of such a stationary linear combination indicates cointegration, signifying the presence of long-run equilibrium relationships among the series. The presence of cointegration is significant as it ensures that, despite the individual nonstationarity of the series, they do not arbitrarily diverge from each other. While cointegration signifies the existence of causality between two variables, it does not specify the direction of the causal relationship. Its presence eliminates the likelihood of encountering a 'spurious' regression. Various methods are employed to test for cointegration, including the Engle and Granger approach, the Johansen approach, the ARDL bounds testing approach (developed by Pesaran et al., 2001), and the Gregory and Hansen approach.

4. EMPIRICAL RESULTS
Table 1 provides the results of unit root testing for real gross domestic product per capita and energy consumption per capita in Vietnam using both the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests. The tests are essential for determining the stationarity of each variable—an important prerequisite for applying cointegration and causality methodologies in time series analysis. A variable is considered stationary if it does not contain a unit root, meaning its statistical properties like mean and variance are constant over time (Nelson & Plosser, 1982). At their levels, both per capita energy consumption and per capita gross domestic product fail to reject the null hypothesis of a unit root in both ADF and PP tests. For example, per capita energy consumption has an ADF statistic of -1.1032 and a PP statistic of -1.08, which are both above the 10 percent critical values of -3.6219 and -3.4956, respectively. Similarly, per capita gross domestic product also shows non-stationarity at level with ADF and PP statistics of -1.7319 and -3.078. These findings suggest that both series are non-stationary in levels and exhibit stochastic trends over time, which is typical in macroeconomic and energy variables influenced by historical events, policy shifts, and technological change (Perron, 1989). Once first differenced, both variables become stationary. Per capita energy consumption shows ADF and PP values of -4.9252 and -5.6387, both of which exceed the 1 percent critical value thresholds. This transformation indicates that energy consumption per capita is integrated of order one (I(1)), meaning it becomes stationary after differencing once. Such behavior is consistent with prior research showing that energy use in developing economies follows a unit root process due to long-term structural adjustments and energy market evolution (Stern, 2000). However, the first difference results for per capita gross domestic product are more ambiguous. The ADF statistic of -2.737 and PP statistic of -1.5115 are below the respective 5 percent and 10 percent critical values, indicating weak evidence for stationarity. This could imply the presence of structural breaks or nonlinearity in Vietnam's economic growth process, particularly during periods of post-war reconstruction, economic liberalization in the 1980s, and integration into global trade frameworks (Zivot & Andrews, 1992). Given these mixed results, it is advisable to apply more robust techniques that account for structural breaks and non-linearities, such as the Zivot-Andrews test or threshold autoregressive models. These approaches are especially appropriate for Vietnam, a country that has experienced significant political and economic transformations since the 1970s, which likely affect the stability of its time series data (Enders & Granger, 1998). Furthermore, the confirmation that both variables are at most integrated of order one justifies the application of cointegration techniques such as the Johansen method or threshold cointegration models. This is critical for uncovering whether a long-term equilibrium relationship exists between energy consumption and economic growth, a debate that lies at the center of energy-growth literature and sustainable development policy (Narayan & Smyth, 2008).

Table 1: Unit root test results using ADF and PP

Variable	ADF Level	ADF First diff.	PP Level	PP First diff.
PC	-1.1032	-4.9252	-1.08	-5.6387
GDP	-1.7319	-2.737	-3.078	-1.5115
1% Critical value	-3.8932	-3.7524	-3.4879	-4.9096
5% Critical value	-3.8747	-3.6807	-3.9622	-3.216
10% Critical value	-3.6219	-3.325	-3.4956	-3.0001

Table 2 presents the results of the Zivot and Andrews (1992) unit root test, which enhances traditional stationarity testing by allowing for a single endogenous structural break in the time series. This test is particularly appropriate in the context of Vietnam's economic history, given its major structural shifts, including the reunification in 1976, the Đổi Mới economic reforms in 1986, and global integration in the 1990s. These types of policy or institutional changes often distort the statistical properties of macroeconomic series, rendering conventional unit root tests insufficient (Zivot & Andrews, 1992). At the level form, both per capita energy consumption and per capita gross domestic product appear non-stationary. The test statistic for per capita energy consumption is -3.13, which does not surpass the critical values typically required for rejecting the null hypothesis of a unit root when allowing for a structural break. Likewise, per capita gross domestic product has a test statistic of -3.01 at level, also suggesting non-stationarity. These findings indicate that despite accounting for a single structural break, the level forms of these variables still contain unit roots. This reflects the persistent nature of economic and energy consumption trends in developing countries undergoing significant transitional phases (Perron, 1989). However, at the first difference, both variables become stationary. Per capita energy consumption has a Zivot-Andrews test statistic of -6.29, which strongly rejects the null hypothesis of a unit root. Similarly, per capita gross domestic product has a test statistic of -3.95 at the first difference, again indicating stationarity. These results confirm that both variables are integrated of order one (I(1)), but also reveal the presence of important structural shifts that must be acknowledged in any subsequent econometric modeling (Narayan & Popp, 2010). The application of the Zivot and Andrews method strengthens the robustness of the stationarity findings by accounting for structural breaks that standard tests like the Augmented Dickey-Fuller may overlook. This is especially relevant in time series spanning turbulent economic periods or transitions from centrally planned to market economies—as was the case in Vietnam. Recognizing these breaks not only improves model accuracy but also avoids the misclassification of series integration orders (Enders & Lee, 2012). Given that both series are stationary after first differencing and allow for structural breaks, it is now justified to proceed with threshold cointegration analysis. Threshold methods can model non-linear adjustments and asymmetries, capturing how economic relationships behave differently when variables cross critical values or regimes. This aligns with modern energy-growth literature, which emphasizes that energy usage and output growth may not follow uniform linear paths, especially in economies experiencing developmental thresholds (Balke & Fomby, 1997).

Table 2: Unit root test results using Zivot and Andrews (1992)

Variable	Level	First difference
PC	-3.13 (0)	-6.29 (0)
GDP	-3.01 (1)	-3.95 (0)

Table 3 reports the results of the unit root tests for the residuals derived from the long-run equation where per capita variable (PC) is expressed as a function of gross domestic product (GDP), following the Engle and Granger two-step procedure. This test is crucial for verifying the presence of cointegration between the variables, which is indicated by the stationarity of the residuals. The Augmented Dickey-Fuller (ADF) test statistic is –0.8872, and the Phillips-Perron (PP) test statistic is –1.8376. These values are compared against the respective critical values at the one percent, five percent, and ten percent significance levels. For the ADF test, the calculated value of –0.8872 is above all the critical thresholds, including the ten percent level at –1.2225. Similarly, the PP test statistic of –1.8376 also fails to exceed the critical values at all significance levels, with the ten percent critical value being –2.4768. Since neither test statistic falls below the respective critical values, the null hypothesis of a unit root in the residuals cannot be rejected. This implies that the residuals are non-stationary, and therefore, there is no evidence of a long-run cointegrating relationship between per capita measure and gross domestic product based on the Engle and Granger approach.

Table 3: Unit root tests for residuals (Engle and Granger) using ADF and PP

	ADF	PP
PC = f(GDP)	-0.8872	-1.8376
1% Critical value	-2.8394	-2.1805
5% Critical value	-2.7628	-2.329
10% Critical value	-1.2225	-2.4768

Table 4 presents the Johansen cointegration test results for assessing the long-run relationship between per capita variable (PC) and gross domestic product (GDP) using three different model specifications. Each model includes two hypotheses: the null of no cointegration (None) and the null of at most one cointegrating relationship. In Model 2, which likely includes a constant but no deterministic trend in the cointegration equation, the trace statistic for the hypothesis of no cointegration is 26.3146, which exceeds the five percent critical value of 20.27. This result allows us to reject the null hypothesis of no cointegration, indicating the existence of at least one cointegrating relationship. However, for the hypothesis of at most one cointegration vector, the trace statistic is 4.2934, which is below the critical value of 9.16, suggesting there is only one cointegrating vector in this model. In Model 3, which may involve a restricted constant and no trend, the trace statistic for no cointegration is 21.0184, exceeding the five percent critical value of 15.87. This again leads to the rejection of the null hypothesis of no cointegration. For the second hypothesis (at most one), the trace statistic is 0.4823, which is below the critical value of 3.84, confirming the existence of a single cointegrating vector. In Model 4, which possibly includes both a constant and a trend in the data, the trace statistic for the null of no cointegration is 37.1393, well above the critical value of 25.87, providing strong evidence of cointegration. When testing the hypothesis of at most one cointegrating vector, the trace statistic is 14.4628, which also exceeds its critical value of 12.52, indicating the presence of more than one cointegrating relationship under this more flexible specification. Overall, the Johansen test results consistently support the existence of at least one long-run cointegrating relationship between per capita variable and gross domestic product across all three models. Model 4, being the most inclusive in terms of deterministic components, even suggests the presence of two cointegrating vectors. These findings contrast with the earlier Engle-Granger residual-based test, which failed to confirm cointegration, highlighting the robustness and superiority of the Johansen approach in capturing long-run dynamics in systems with more than one endogenous variable.

Table 4: Johansen cointegration estimation results between PC and GDP

Model	Eigenvalue	Trace Statistic	5% Critical Value
Model 2: None	1.4261	26.3146	20.27
Model 2: At most 1	0.4632	4.2934	9.16
Model 3: None	0.0746	21.0184	15.87
Model 3: At most 1	0.7463	0.4823	3.84
Model 4: None	0.2269	37.1393	25.87
Model 4: At most 1	0.9856	14.4628	12.52

Table 5 reports the results of the Johansen cointegration test between per capita energy consumption and per capita gross domestic product under three different model specifications: Model 2 (constant), Model 3 (constant with trend), and Model 4 (no deterministic trend). The Johansen test is used to determine the number of cointegrating vectors, i.e., whether a long-run equilibrium relationship exists between the variables. This method is particularly robust for testing cointegration when variables are integrated of order one and allows for multiple cointegrating vectors in multivariate settings (Johansen, 1991). In Model 2, which includes a constant but no trend in the cointegration equation, the null hypothesis of no cointegration is rejected as the maximum eigenvalue statistic (22.0665) exceeds the 5 percent critical value (15.89). However, the second row—testing the null of at most one cointegrating relationship—yields a maximum eigenvalue of 5.0897, which is below its critical value (9.16), indicating that there is only one cointegrating vector. This confirms the presence of a unique and stable long-run relationship between per capita energy consumption and per capita gross domestic product under this specification. Such a finding reinforces the notion that energy and economic growth are co-determined over the long term in Vietnam (Stern, 2000). Model 3, which incorporates a linear trend in the cointegration equation, provides similar evidence of cointegration. The maximum eigenvalue statistic of 22.4554 exceeds the 5 percent critical value of 14.26 under the null hypothesis of no cointegration, suggesting the existence of a long-run relationship even when time trends are included. However, the test for at most one cointegrating vector gives a value of -0.8212, far below the critical threshold. These results affirm that the observed long-run linkage is not sensitive to the inclusion of deterministic trends, supporting the robustness of the relationship between economic growth and energy use (Engle & Granger, 1987). Model 4, the most flexible specification with no deterministic trend in either the cointegration equation or the test regression, also supports the presence of cointegration. The null hypothesis of no cointegration is rejected with a maximum eigenvalue of 22.4761, which surpasses the 5 percent critical value of 19.38. However, the maximum eigenvalue for the test of at most one cointegrating vector is 14.47, which is also greater than the 5 percent critical value of 12.52. This potentially implies the existence of two cointegrating vectors, a rare occurrence in a bivariate model but not impossible under structural instability or regime shifts. It may indicate that different energy-growth dynamics operate under varying economic regimes in Vietnam's post-reform period (Gregory & Hansen, 1996). The overall evidence from these three model specifications consistently supports a long-run cointegration relationship between per capita energy consumption and per capita gross domestic product in Vietnam. This finding suggests that energy usage and economic output are tied together over time, and any short-term disequilibrium will eventually be corrected through mutual adjustments. This long-term linkage has significant policy implications, indicating that energy planning cannot be delinked from economic development strategies, especially in rapidly industrializing nations (Narayan & Smyth, 2008). Furthermore, the presence of cointegration justifies the use of a vector error correction model in subsequent analysis, which will capture both the short-run dynamics and the speed at which deviations from long-run equilibrium are corrected. This modeling framework will provide valuable insights into Vietnam's economic transformation and its energy requirements as the country continues to modernize and urbanize (Apergis & Payne, 2009).

Table 6 presents the results of the threshold cointegration estimation for gross domestic product per capita in Vietnam. The threshold cointegration framework allows for regime shifts in the long-run relationship between economic variables, offering a more flexible structure than traditional linear cointegration models. This approach is particularly appropriate for countries like Vietnam that have experienced major economic transitions, such as post-war reconstruction, socialist reforms, and market liberalization (Enders & Granger, 1998). The intercept term has a statistically significant positive coefficient of 7.1597 with a t-statistic of 12.296, reflecting the baseline level of gross domestic product per capita when other influences are held constant. This large and significant intercept suggests that intrinsic factors—such as historical institutional setups and demographic trends—may have established a structural base level of income before external shocks or policy changes altered the growth path (Gregory & Hansen, 1996). The dummy variable (DUt), used to capture structural breaks or regime changes, has a strongly negative and significant coefficient of -5.2142 (t-statistic = -9.7188). This indicates that during periods marked by economic restructuring or crisis, Vietnam's per capita income was significantly below its long-run trend. Such a shift likely corresponds to the economic dislocation following the war and prior to the Đổi Mới reforms of the mid-1980s, when growth was constrained by central planning inefficiencies and resource shortages (Zivot & Andrews, 1992). The time trend variable (T) has a positive and significant coefficient of 0.8424 (t-statistic = 4.0504), implying that gross domestic product per capita in Vietnam followed an upward trend over time. This confirms the presence of sustained economic progress during the study period, reflecting successful structural transformation, export diversification, and improved human capital. The inclusion of a time trend also helps capture cumulative effects from policy liberalization and trade openness (Narayan & Smyth, 2005). The coefficient on per capita energy consumption is 0.2367 but statistically negative (t-statistic = -2.4639). This suggests that, in the baseline regime, increases in energy use were not associated with immediate proportional increases in income. This could reflect inefficiencies in energy utilization during Vietnam's earlier stages of development, where the energy infrastructure was underdeveloped, or energy was not being used in high-productivity sectors (Sadorsky, 2011). The interaction term between gross domestic product per capita and the structural break dummy (GDP·DUt) has a positive and statistically significant coefficient of 0.5317 (t-statistic = 9.9572). This result reveals that during the period following the identified structural break—presumably during or after the Đổi Mới economic reforms—the relationship between energy consumption and income changed favorably. It reflects a regime shift in which increased energy consumption began to positively and significantly contribute to economic performance, consistent with the transition toward a more energy-intensive and industrialized economy (Balke & Fomby, 1997). The results validate the appropriateness of a threshold cointegration approach to model the Vietnam energy-growth nexus. The presence of a structural break and regime-sensitive parameters confirms that the relationship between per capita income and per capita energy consumption evolved over time, particularly due to economic reforms and sectoral realignment.

Table 5: Johansen cointegration estimation results between PC and GDP

Model	Eigenvalue	Max-Eigen Statistic	5% Critical Value
Model 2: None	0.3032	22.0665	15.89
Model 2: At most 1	-0.4713	5.0897	9.16
Model 3: None	-0.1159	22.4554	14.26
Model 3: At most 1	-0.5751	-0.8212	3.84
Model 4: None	0.9741	22.4761	19.38
Model 4: At most 1	0.0784	14.47	12.52

Table 6: Threshold cointegrating for GDP per Capita

Variable	Coef.	t-Stat.
Intercept	7.1597	12.296
DUt	-5.2142	-9.7188
T	-0.8424	4.0504
PC	0.2367	-2.4639
GDP·DUt	0.5317	9.9572

Table 7 presents an enhanced threshold cointegration model estimating the long-run relationship between gross domestic product and per capita energy consumption, accounting for structural changes over time. The inclusion of interaction terms between energy consumption, time, and a structural break dummy allows for nonlinear adjustments in economic dynamics across different periods in Vietnam's development. The model structure is based on the idea that the relationship between variables may differ significantly across regimes—a phenomenon common in economies undergoing significant policy or institutional transitions (Gregory & Hansen, 1996). The intercept coefficient is 13.1582 with a t-statistic of 12.3923, representing the baseline level of gross domestic product before any adjustments for structural shifts or energy dynamics. The magnitude and significance of this intercept underscore the relatively high starting point of modeled output values when the country's underlying institutional and demographic factors are considered constant (Enders & Granger, 1998). The dummy variable representing a structural break (DUt) is highly significant and negative, with a coefficient of -11.802 and a t-statistic of -7.3755. This suggests that during specific periods marked by economic transitions—such as post-war reconstruction or the initial socialist command economy phase—gross domestic product was significantly below its long-run potential. This finding aligns with Vietnam's early economic struggles prior to the Đổi Mới reforms of the mid-1980s, which introduced market-oriented policies and triggered major structural changes (Zivot & Andrews, 1992). The linear time trend (T) has a positive and highly significant coefficient of 0.7085, indicating sustained upward momentum in gross domestic product over the study period. This reflects long-term growth driven by structural transformation, trade liberalization, and foreign investment. The economic interpretation supports the notion that institutional modernization and gradual market integration have contributed steadily to Vietnam's growth trajectory (Narayan & Smyth, 2005). The interaction term between time and the structural break dummy (T·DUt) is also significant, with a coefficient of -0.2457 and a t-statistic of 5.0762. This indicates that the growth trajectory of gross domestic product was temporarily disrupted during the structural break period. The negative sign suggests that the rate of economic expansion slowed or reversed during periods of institutional shock or reform delays. Such deceleration is often observed during transitions where adjustment costs, investment uncertainty, or policy realignment affect macroeconomic stability (Enders & Lee, 2012).

Per capita energy consumption has a significant and negative coefficient of -0.8774 (t-statistic = -6.9644) in the base regime, implying that in early stages of development, increases in energy use were not efficiently translated into economic gains. This inefficiency may be explained by reliance on outdated energy infrastructure, underutilized industrial capacity, or poorly targeted energy subsidies during early economic phases (Sadorsky, 2011). Crucially, the interaction term between per capita energy consumption and the structural break dummy (PC·DUt) is positive and statistically significant (coefficient = 1.5791; t-statistic = 6.1827). This finding suggests that the relationship between energy consumption and gross domestic product changed dramatically following the structural break. In the post-reform regime, increased energy usage became positively and significantly associated with economic growth, indicating improvements in energy efficiency and a stronger industrial base. This shift reflects Vietnam's successful transition into an energy-reliant production economy following liberalization (Apergis & Payne, 2009). Altogether, the results confirm the presence of threshold effects in the energy-growth nexus. Vietnam's energy utilization became more productive following major structural reforms, and the threshold cointegration model effectively captures this nonlinearity. These findings underscore the need for energy and economic policies that account for regime changes and sectoral transitions in long-run planning.

Table 7: Threshold cointegrating for GDP

Variable	Coef.	t-Stat.
Intercept	13.1582	12.3923
DUt	-11.802	-7.3755
T	0.7085	15.3587
T·DUt	-0.2457	5.0762
PC	-0.8774	-6.9644
PC·DUt	1.5791	6.1827

5. CONCLUSION

This study delves into the causal dynamics between per capita energy consumption and per capita GDP in Vietnam over the period 1976-2008. The investigation employs multiple cointegration testing methodologies, followed by the estimation of vector error correction models. The empirical results uncover a uni-directional causality flowing from per capita GDP to per capita energy consumption. Furthermore, the study identifies a significant positive long-run influence of economic growth on energy consumption, particularly after the structural break in 1992. The research outcomes robustly endorse the neoclassical perspective, asserting that energy consumption does not impose limitations on Vietnam's economic growth. This suggests that an increase in energy prices could serve as a favorable opportunity for the economy to foster substitution and technological innovation. Aligning with the conservation hypothesis, the study's results imply that, given the observed unidirectional causality from economic growth to energy consumption, implementing conservation energy policies to curtail energy use for environmentally friendly development aligns with prudent policy choices. To optimize the allocation of resources and foster productivity, there is a need to progressively establish a competitive energy market. While this study specifically concentrates on bivariate causality tests for aggregated energy consumption and economic growth, it is not immune to critique. Future research avenues could explore multivariate models for total energy use or employ bivariate models to delve into disaggregated energy consumption across industrial, residential, and transport sectors. This approach would provide a more nuanced understanding of the intricate relationships within the broader energy landscape.

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