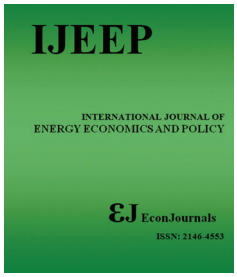

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Nexus of Trade, FDI, Green Energy, Green Tax and Environmental Quality in Vietnam: A Time Varying Granger Causality

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ABSTRACT

This paper explores the time-varying causal relationship between environmental quality and key economic indicators, including trade, foreign direct investment (FDI), green energy, and green tax in Vietnam over the period 2005-2020. Utilizing forward recursive, rolling window, and recursive evolving Granger causality techniques, the study reveals that the causal nexus between environmental and economic variables is dynamic and context dependent. The findings show that environmental quality does not Granger-cause trade, while it exerts short-term effects on FDI and green energy, particularly during periods of heightened environmental policy attention. In contrast, trade and green tax significantly influence environmental quality, especially in the aftermath of major policy shifts, such as the implementation of Vietnam's environmental tax law and its commitments under the Paris Agreement. Based on the result, some policy implications are suggested to effectively navigate the evolving relationship between environmental sustainability and economic development in Vietnam.

Keywords: Environmental Quality, Foreign Direct Investment, Green Energy, Green Tax, Time Varying Granger Causality, Trade
JEL Classifications: Q56; F18; C22; H23

1. INTRODUCTION

As Vietnam integrates more deeply into the global economy, trade and FDI have played pivotal roles in driving economic growth. However, these factors also exert significant influence on environmental quality. Vietnam's CO_2 emissions rose from 56.5 million tons in 2000 to 372.9 million tons in 2023 (World Bank, 2025), representing more than a sixfold increase over two decades. Today, Vietnam is one of the most open economies in the world, with approximately 50% of its GDP and employment dependent, either directly or indirectly, on exports. Export-related emissions now account for over one-third of Vietnam's total CO_2 emissions, a proportion that surpasses that of any comparable country in the region. More seriously, this figure has exceeded those of China, South Korea, Thailand, Indonesia, Malaysia, and the Philippines since 2000 (Bao, 2024). In addition, by the end of 2024, foreign investors had invested in 19 out of 21 sectors in Vietnam's national economic classification system, with the processing and manufacturing sectors attracting the highest share - over USD 308.76 billion, accounting for 61.4% of total FDI capital (Ministry of Planning and Investment, 2025). However, processing and manufacturing sectors can cause pollution to the environment. In recent years, the promotion of green energy is widely regarded as a key solution to mitigating negative environmental impacts. Meanwhile, green tax, as economic policy instruments, are designed to internalize environmental costs into the prices of goods and services, encourage environmentally friendly behaviour, and generate revenue for environmental protection activities (Pearce, 1991). At COP26, Vietnam pledged to achieve net-zero carbon emissions by 2050 and has since actively promoted green energy investment and environmental taxation. Therefore, investigating the dynamic relationships between trade, FDI, green energy, green tax, and environmental quality is of crucial practical importance.

The dynamic interactions among trade openness, FDI, green energy, green tax, and environmental quality have attracted

growing academic interest within the broader literature on sustainable development and environmental economics. However, green energy and environmental tax, despite their increasing relevance to climate policy, are often underrepresented in nexus studies. Furthermore, there have been many studies on the impact of factors such as trade and FDI on environmental quality (Ali, 2015; Zomorrodi and Zhou, 2017; Dingiswayo et al., 2023), while the reverse effect, the impact of environmental quality on these factors has received relatively little attention. This highlights the need to supplement existing research with studies exploring the causal relationship between environmental quality and other factors. Moreover, limited attention has been paid to emerging economies such as Vietnam, highlighting the need for further research on the nexus of trade, FDI, green energy, green tax, and environmental quality. In addition, most existing studies rely on static econometric approaches such as ARDL (Ho and Ho, 2021; Minh et al., 2023; Phuc, 2024), Pooled OLS, FEM, REM (Atici, 2012; Huang et al., 2019; Long Ma, 2023) which primarily test one-directional causal relationships. These methods are inadequate in capturing the time-varying and potentially bidirectional nature of interactions between environmental quality and key economic variables. Time-varying Granger causality is a relatively underutilized yet powerful econometric technique in the field of environmental and green economy research. It addresses the limitations of static models by allowing the detection of causal relationships that evolve over time in terms of both direction and intensity (Shi et al., 2020). This flexibility is particularly valuable for Vietnam - a rapidly transforming economy where green policies and sustainable initiatives are gradually implemented and may produce varying effects across different periods. Because of the above reasons, it is crucial and necessary to undertake the research on the nexus of trade, FDI, green energy, green tax, and environmental quality, using time-varying Granger causality in the Vietnamese context.

2. LITERATURE REVIEW

2.1. Trade and Environmental Quality

In economic and environmental studies, environmental quality is commonly assessed indirectly through indicators of air pollution, with carbon dioxide (CO_2) emissions per capita being the most widely used metric (Shahbaz et al., 2016; Ho and Ho, 2021; Yameogo et al., 2021). Karsalari et al. (2014) examined the causal relationship between environmental quality, economic growth, and trade in D8 countries, finding that while emissions are positively associated with trade in the long run, there is no evidence of causality between them. More recent studies have adopted time-varying Granger causality approaches to capture the dynamic relationships between trade, environmental quality, and related factors. For example, Ali (2015) reported a bidirectional causal relationship between trade openness and CO_2 emissions in Pakistan. In contrast, Hakimi and Hamdi (2020) found that trade has no significant impact on environmental quality. Ike et al. (2020) demonstrated that higher trade volumes contribute to increased emissions in G7 countries. Similarly, Dingiswayo et al. (2023) observed a positive relationship between trade openness and CO_2 emissions in South Africa, with unidirectional causality running from trade to environmental quality. Another research from Thi Quy et al. (2024) identified a bidirectional, time-varying causal relationship between trade openness and CO_2 emissions in Thailand. Consistent with prior research, Wang et al. (2024) found that the environmental impact of trade in China evolves over time, initially worsening environmental quality, but improving later as environmental policies become more stringent. Overall, the literature presents mixed and context-dependent evidence regarding both the direction and existence of causality between trade and CO_2 emissions.

2.2. FDI and Environmental Quality

Recent studies have investigated the complex and context-specific relationship between FDI and environmental quality across various countries. Ali (2015) found that both trade openness and FDI in Pakistan exhibit a bidirectional causal relationship with CO_2 emissions. In India, Kumar (2016) employed a Granger causality test and discovered that FDI inflows have a significant negative impact on air quality. Similarly, Hamid (2016) reported a bidirectional causality between FDI and CO_2 emissions in Pakistan, with FDI contributing to higher emissions in both the short and long term. However, contrasting evidence comes from a study of European countries by Jugurnath et al. (2017), which revealed a positive relationship between FDI and environmental tax revenues, implying that the increase in FDI may enhance environmental governance. In China, Zomorrodi and Zhou (2017) found that FDI has a significant but weak positive relationship with air pollution (sulphur dioxide), while no significant link was observed with water pollution. Fakhreldin and Elsawy (2018) demonstrated a negative bidirectional causal relationship between environmental regulations and FDI in China, suggesting a regulatory push-pull effect. Furthermore, Rana and Sharma (2020), using the Modified Wald (MWALD) test, concluded that FDI contributes to environmental degradation in India by increasing CO_2 emissions and energy consumption, thus supporting the Pollution Haven Hypothesis. In summary, the literature reveals mixed and contradictory findings about the relationship between FDI and environmental quality.

2.3. Green Energy and Environmental Quality

Granger causality tests reveal mixed and context-specific results when examining the relationship between renewable energy consumption and CO_2 emissions. Kulionis (2013), using annual data from 1972 to 2012 in Denmark, found that renewable energy consumption Granger-causes CO_2 emissions, suggesting a dynamic link between the two variables. In Tunisia, Ben Jebli and Ben Youssef (2017) identified long-run bidirectional causalities among all variables studied while renewable energy consumption reduces CO_2 emissions, non-renewable energy use, trade, and agricultural value added contribute to higher emissions. In the European Union, Lee (2018) observed that renewable energy consumption has a significant negative long-run impact on CO_2 emissions. Similarly, Shan et al. (2021) found that renewable energy use effectively reduces CO_2 emissions in Turkey. Chen et al. (2022) further advanced this understanding by demonstrating that the negative and significant impact of renewable energy consumption on CO_2 emissions only emerges once a country surpasses a certain threshold of renewable energy use per capita. On a global scale, Caldera et al. (2024) reported the existence

of both bidirectional and unidirectional causalities among GDP, renewable energy consumption, and CO_2 emissions, depending on the region and period of analysis. In summary, while renewable energy generally contributes to lower CO_2 emissions, the strength and direction of this relationship vary across countries and depend on broader economic and policy contexts.

2.4. Green Tax and Environmental Quality

In empirical research on environmental policy and fiscal instruments, green tax is commonly measured as government revenues from environmental taxes on energy, transport, pollution, and resource consumption, expressed as a percentage of GDP. This composite indicator captures the degree to which environmental taxation is embedded within a country's fiscal framework and reflects its potential to influence environmental quality (OECD, 2019). According to OECD (2024), environmental taxes generally encompass energy taxes (e.g., fossil fuel levies), transport taxes (e.g., vehicle registration fees), pollution taxes (e.g., CO_2 or waste emissions), and resource taxes (e.g., charges on water or minerals). Recent studies have investigated the relationship between environmental taxes and environmental quality. For example, Depren et al. (2022) examined Nordic countries and found that the effects of disaggregated environmental taxes on CO_2 emissions vary significantly across countries and income quantiles. Bădîrcea et al. (2020) compared Romania and Sweden, concluding that environmental taxes contribute to long-run reductions in greenhouse gas emissions. Similarly, Wolde-Rufael and Mulat-Weldemeskel (2021) showed that environmental taxes combined with stringent environmental regulations can effectively reduce CO_2 emissions in emerging economies. Chen et al. (2022) provided cross-country evidence that environmental taxes and regulatory stringency improve environmental quality, particularly within OECD nations. Using a dynamic panel threshold model for 34 OECD countries, Al Shammre et al. (2023) demonstrated that environmental taxes reduce CO_2 emissions significantly when their share of GDP exceeds a critical threshold. More recently, Akdag and Alola (2024) confirmed the positive environmental impact of green taxation in EU countries, further reinforcing its policy relevance. Overall, these findings suggest that green tax is a practical tool for guiding environmental policy to improve environmental quality.

3. RESEARCH METHODOLOGY AND DATA

3.1. Research Methodology

This study employs a time-varying Granger causality test to examine the causal effects between trade, FDI, green energy, green tax, and environmental quality. The reason for choosing the time-varying Granger causality method is that the causality among the variables may show dynamic characters (Hammoudeh et al., 2020). Moreover, time-varying Granger causality can capture multiple structural breaks in the data with having possible shifts in parameters in specific periods (Balcilar et al., 2010). The lag-augmented VAR (LA-VAR) approach to performing Granger causality tests (Toda and Yamamoto, 1995; Dolado and Lütkepohl, 1996). For the Granger causality method with variation in time, several techniques exist, such as the forward expanding window test (Thoma, 1994), rolling window Granger causality test (Swanson, 1998), and recursive rolling Granger causality (Shi et al., 2018; Shi et al., 2020). Combining these three techniques provides a comprehensive and robust framework for identifying both stable and time-varying causal relationships, enhancing the reliability and depth of the empirical findings. The LA-VAR model is as follows:

$$y_{1t} = \varnothing_0^{(1)} + \sum_{k=1}^{m} \phi_{1k}^{(1)} y_{1t-k} + \sum_{k=1}^{m} \phi_{2k}^{(1)} y_{2t-k} + \varepsilon_{1t} \quad (1)$$

$$y_{2t} = \varnothing_0^{(2)} + \sum_{k=1}^{m} \phi_{1k}^{(2)} y_{1t-k} + \sum_{k=1}^{m} \phi_{2k}^{(2)} y_{2t-k} + \varepsilon_{2t} \quad (2)$$

where, y_{1t} denotes the Environmental quality and y_{2t} denotes trade, FDI, green energy, green tax in each test.

The null hypothesis of Granger causality between y_1 to y_2 is tested by using the Wald test for joint significance of $\phi_{1k}{}^{(2)} (k = 1\ldots, m)$.

Shi et al. (2018) developed an additional test based on the supremum norm (sup) of the recursive evolutionary Wald statistic. Let f_1 be the starting point of the regression and f_2 the end point of the regression. The sup Wald statistic is expressed as follows:

$$\underset{f}{SW}(f_0) = \frac{sup}{(f_1, f_2) \in \hat{O}, f_2 = f} \{\omega_{f_2}(f_1)\} \quad (3)$$

where, $\hat{O} = \{(f_1, f_2): 0 < f_0 + f_1 \leq f_2 \leq 1, and\ 0 \leq f_1 \leq 1 - f_0\}$, and $w_{f2}(f_1)$ is the *Wald* statistic on [f_1, f_2] with sample capacity fraction f_w, which is shown as follows:

$$f_w = f_2 - f_1 \geq f_0 \quad (4)$$

It is worth noting that this procedure allows for a relaxation of f_1 and therefore allows for flexible application of re-initialization for each sub-sample. The start of causality (subdivision) indicates the first observation whose test statistic is above (below) its corresponding critical value.

Although Shi et al. (2020) propose that the recursive evolving window procedure (Phillips et al., 2015a; Phillips et al., 2015b) performs better than the forward expanding (Thoma, 1994) and the rolling window (Swanson, 1998) procedures, all three procedure results based on the below test statistics also suggested by Hammoudeh et al. (2020) which are taken into account in our study.

The test statistics for the forward expanding window procedure is as follows:

$$\hat{f}_e = \frac{inf}{f \in [f_0, 1]} \{f : W_f(0) > cv\}\ and \hat{f}_f = \frac{inf}{f \hat{o} [\hat{f}_e, 1]} \{f : w_f(0) < cv\} \quad (5)$$

The test statistics for the rolling window procedure is as follows:

$$\hat{f}_e = \frac{inf}{f \in [f_0, 1]} \{f : W_f(f - f_0) > cv\}\ and \hat{f}_f = \frac{inf}{f \varepsilon [\hat{f}_e, 1]} \{f : w_f(f - f_0) < cv\} \quad (6)$$

The test statistics for the recursive evolving procedure is as follows:

$$\hat{f}_e = \frac{inf}{f \in [f_0,1]}\{f : SW_f(f_0) > scv\} and \hat{f}_f = \frac{inf}{f \varepsilon [\hat{f}_e,1]}$$

$$\{f : SW_f(f_0) < scv\} \quad (7)$$

3.2. Data Collection

Yearly data was collected from 2003 to 2020 because of the available data in collected sources. The Table 1 below shows the variables' description, measuring units and sources.

A major requirement for rolling or recursive causality tests is a sufficiently large number of time series observations, typically available only with monthly or quarterly data (Balcilar et al., 2010). Therefore, the collected yearly data is changed to monthly data. In addition, given that the time-varying Granger method allows for more flexibility in time series data, logarithmic transformations to the variables are applied (Ren et al., 2023). The logarithmic transformation for all the variables helps decrease the heteroscedasticity and non-normality.

4. RESULTS AND DISCUSSION

4.1. Descriptive Statistics

The trade from 2003 to 2020 in Vietnam is showed in Figure 1. From 2003 to 2007, the percentage of trade in GDP increased each year. However, this figure decreased from 2008 to 2010. After that, it experienced a dramatic rise during the period from 2011 to 2020.

FDI from 2003 to 2020 in Vietnam is showed in Figure 2. This figure, after reaching its peak in 2008, declined significantly in the following years.

Green energy from 2003 to 2020 in Vietnam is showed in Figure 3. This figure shows an upward trend during the period from 2003 to 2017. It declined in 2018 and 2019, then increased in 2020.

Green tax from 2003 to 2020 in Vietnam is showed in Figure 4. From 2015, this figure shows an upward trend compared to the previous period.

Environmental quality from 2003 to 2020 in Vietnam is showed in Figure 5. Total annual emissions of carbon dioxide (CO_2) per capita increased gradually each year.

Table 2 below provides descriptive statistics for the variables. Descriptive statistics for variables include mean, standard deviation, minimum, maximum and normal distribution.

Table 2 presents the descriptive statistics of the main variables used in the analysis. Each variable has 215 observations. The mean values of all variables are close to zero because all variables are logarithmic transformations. The standard deviations indicate varying levels of dispersion, with FDI and GRT showing relatively higher variability compared to other variables. The skewness statistics reveal that FDI, GRT, and ENQ are positively skewed, indicating distributions with longer right tails. In contrast, GRE is negatively skewed, while TRA is approximately symmetric. Furthermore, all variables exhibit high kurtosis values.

Table 3 below provides the correlation analysis which shows the correlation among variables.

Table 3 indicates that TRA is positively and significantly correlated with FDI (0.3589), and with GRE at (0.3513), suggesting that greater FDI and GRE are associated with enhanced trade performance and vice-versa. FDI is negatively correlated with GRE (−0.1753), indicating a potential trade-off between FDI and GRE. Additionally, GRE is significantly and negatively correlated with ENQ (−0.5246), suggesting that the increase in GRE may be associated with lower environmental quality, or vice versa. GRT shows weak and mostly insignificant correlations with the other variables, except a negative correlation with GRE (−0.1168). Overall, the matrix suggests moderate relationships among some variables, with limited multicollinearity concerns.

4.2. Unit Root Test Results

Table 4 below displays the unit root test results. To examine the time-varying causality between TRA, FDI, GRE, GRT, and ENQ, we first test for a unit root test in all variables. By doing this, we use ADF and PP tests to take into account the stationarity characteristics of the data series. Table 4 shows that all variables are found to be stationary at their first differences of the logarithm.

4.3. Time-Varying Causality Result

The causal relationships among the variables using forward expanding window method of Thoma (1994), rolling window procedure of Swanson (1998) and recursive evolving procedure of Shi et al. (2018; 2020) are implemented. The Wald test results for the time-varying Granger causality test based on the forward recursive, rolling evolving, and recursive evolving techniques are presented in Tables 5 and 6 below.

Table 1: Description, measuring units, and sources variables

Abbreviation of variables	Description	Measuring units	Data sources
TRA	Trade: the sum of exports and imports of goods and services, measured as a share of GDP	% of GDP	World bank
FDI	Foreign direct investment: FDI net inflows is divided by GDP	% of GDP	World bank
GRE	Green energy: Per capita energy consumption from renewables	kilowatt-hours per person	Our world in data
GRT	Green tax: Government revenues from environmental taxes on energy, transport, pollution and resource consumption measured as a share of GDP	% of GDP	World bank
ENQ	Environmental quality: Total annual emissions of carbon dioxide (CO_2) is divided by the economy's population	tCO_2e/capita	World bank

Figure 1: Trade (% of GDP) from 2003 to 2020 in Vietnam

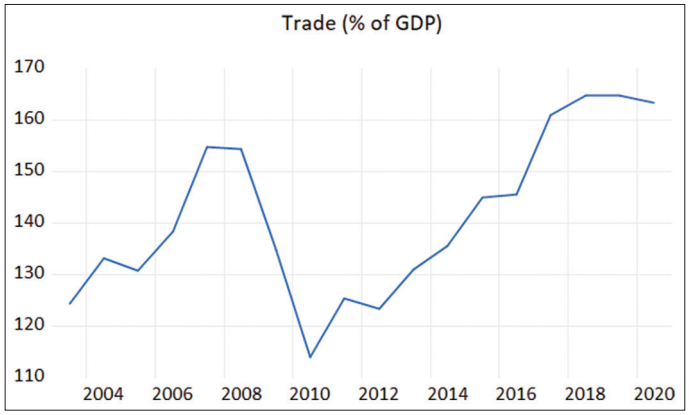


Figure 2: FDI (% of GDP) from 2003 to 2020 in Vietnam

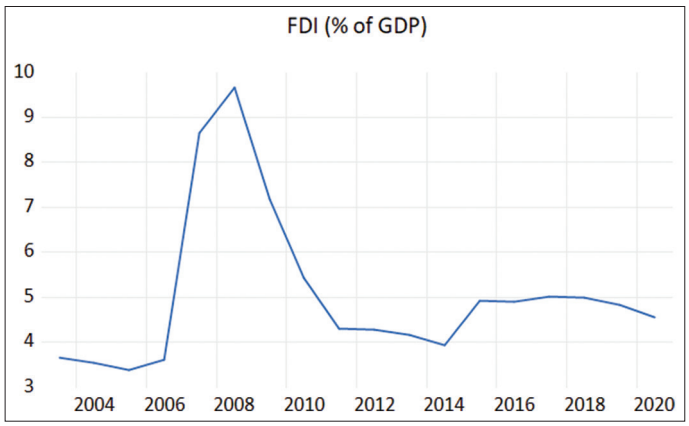
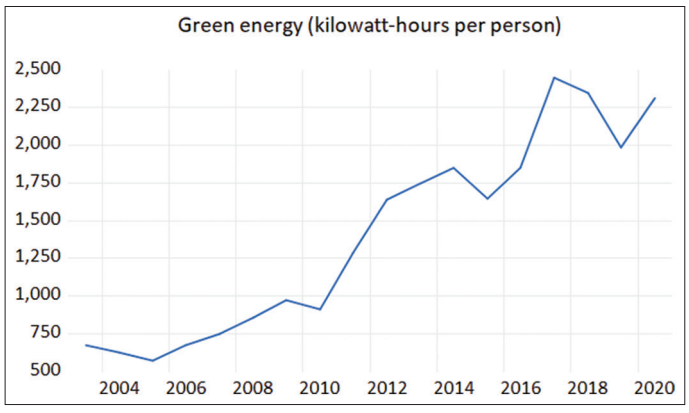


Figure 3: Green energy (kilowatt-hours per person) from 2003 to 2020 in Vietnam



The result in Table 5 indicates that environmental quality does not Granger-cause changes in trade activities. However, it exerts significant influences on other key economic variables. Specifically, ENQ has a strong causal impact on FDI as evidenced by the recursive method. It also demonstrates a consistently significant effect on green energy. In contrast, the influence of environmental quality on green tax is relatively weak, with statistical significance observed only under the recursive framework.

The result in Table 6 indicates that trade and environmental taxation exert a significant influence on environmental quality,

Figure 4: Green tax (% of GDP) from 2003 to 2020 in Vietnam

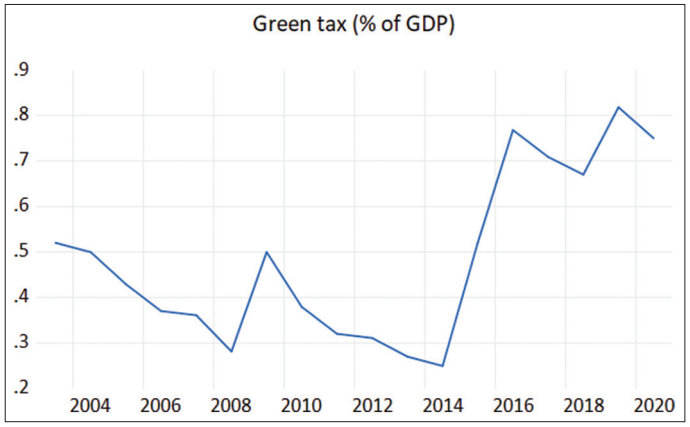
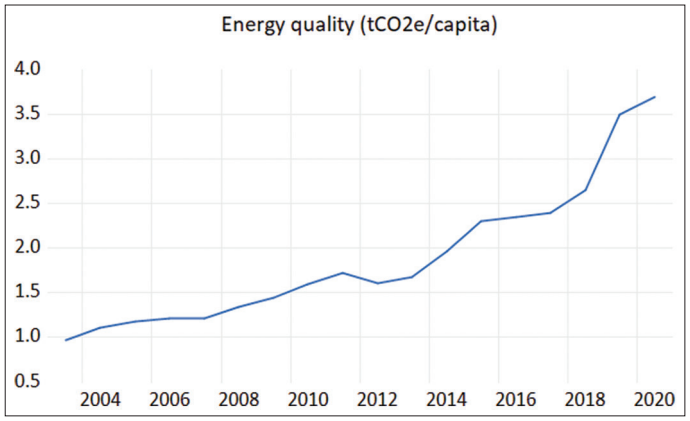


Figure 5: Environmental quality (tCO_2e/capita) from 2003 to 2020 in Vietnam



while FDI and green energy have not demonstrated a clear direct impact.

The causal relationships for each case are elaborated in the following section. Figures 6-13 show the test statistics sequence and the 5% critical value sequence. The null hypothesis of no Granger causality between the 2-time series variable can be rejected if the critical value sequence falls below the test statistics sequence.

4.3.1. Time-varying causality between ENQ and TRA

From ENQ to TRA, Figure 6 below shows that for the forward recursive causality, rolling causality and recursive evolving causality, the null hypothesis of no Granger causality cannot be rejected since the test statistic does not exceed the critical value statistic over the sample period. It means that there is no evidence of Granger causality from ENQ to TRA throughout the entire sample period. This suggests that TRA may be driven by other factors independent of ENQ or that any potential relationship may be nonlinear or indirect.

From TRA to ENQ, Figure 7 below shows that for the forward recursive, TRA did not have the effect on ENQ. However, there is evidence of Granger causality from TRA to ENQ in the period of 2010-2016 for the rolling causality and recursive evolving

Figure 6: Time-varying causality from ENQ to TRA. (a) Forward recursive causality (b) Rolling causality (c) Recursive evolving causality

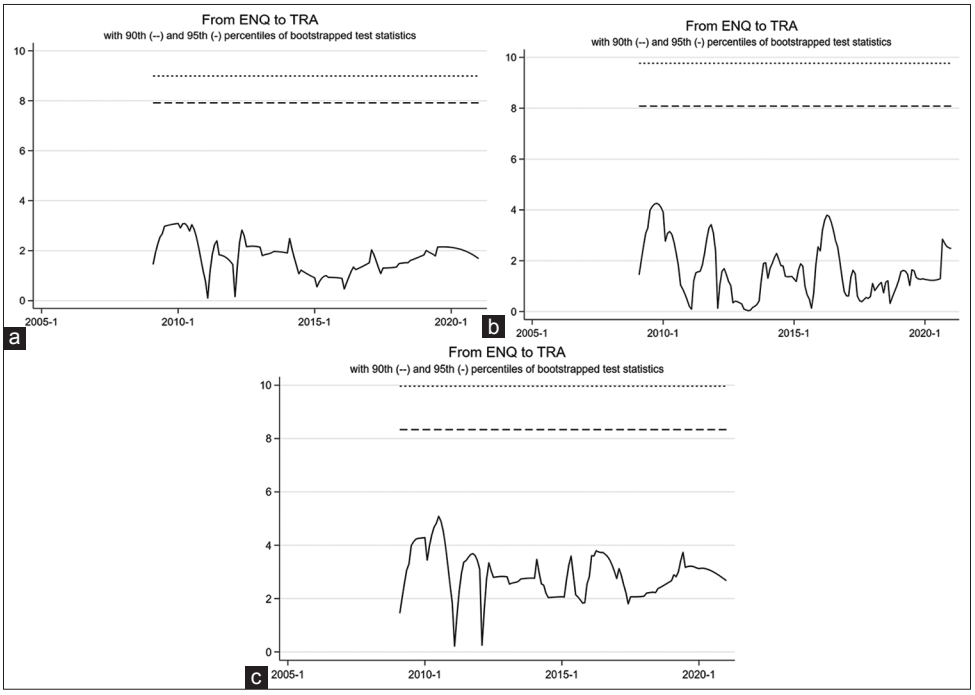


Table 2: Descriptive statistics

Variables	Obs.	Mean	Standard deviation	Min	Max	Skewness	Kurtosis
TRA	215	0.001513	0.010075	−0.059224	0.071537	0.348169	20.95219
FDI	215	0.000804	0.034493	−0.233705	0.312805	2.265372	43.03087
GRE	215	0.006216	0.019850	−0.116598	0.107106	−0.774678	17.31304
GRT	215	0.001112	0.041870	−0.226588	0.318600	1.262232	26.4474
ENQ	215	0.006502	0.009996	−0.04654	0.087683	1.892870	25.99341

The table displays descriptive statistics of the logarithmized monthly variables

Table 3: Correlation analysis

Variables	TRA	FDI	GRE	GRT	ENQ
TRA	1.000				
FDI	0.3589***	1.000			
GRE	0.3513***	−0.1753*	1.000		
GRT	−0.00185	0.0858	−0.1168**	1.000	
ENQ	0.1020	−0.1566**	−0.5246***	0.0595	1.000

All variables are logarithmic.
***, **, and *represent statistical significance at the 1%, 5%, and 10% level, respectively

Table 4: Unit root test results

Variable		ADF	PP
TRA	Intercept	−3.966058***	−8.954482***
FDI		−4.528968***	−9.137038***
GRE		−4.261343***	−8.701113***
GRT		−4.350114***	−9.632117***
ENQ		−3.925889***	−8.095526***
TRA	Trend and intercept	−3.965554***	−8.933912***
FDI		−4.554168***	−9.162462***
GRE		−4.273258***	−8.715338***
GRT		−4.437262***	−9.671551***
ENQ		−3.923301***	−8.088073***

All variables refer to the first difference of the logarithm. ADF and PP indicate Dickey-Fuller and Phillips-Perron, respectively. Superscripts ***signify significance at 1%

causality. The result of the effect of TRA on ENQ is consistent with Ali (2015); Ike et al. (2020) and Wang et al. (2024). The volatility of the relationship from TRA to ENQ can be attributed to multiple factors. During the period from 2010 to 2016, global trade experienced a robust recovery following the 2008-2009 financial crisis, which led to a surge in energy demand driven by increased industrial production and transportation activities. In this context, where Vietnam - a developing country heavily relied on the export of energy-intensive goods, a causal relationship from trade to energy consumption was both plausible and expected. However, since 2016, the structural shift of economies toward service-oriented and high-tech sectors, coupled with the adoption of policies aimed at improving energy efficiency and promoting the use of renewable energy, has reduced dependence on conventional energy sources. Additionally, the disruptive effects of the COVID-19 pandemic may have contributed to weakening or obscuring the causal link between trade and energy consumption.

4.3.2. Time-varying causality between ENQ and FDI

From ENQ to FDI, Figure 8 below indicates that for the forward recursive causality and rolling causality, the test statistic does not exceed the critical value statistic of 95% over the sample period

Table 5: Wald test for Granger causality (dependable variables: TRA, FDI, GRE, GRT)

Causality	Forward			Rolling			Recursive		
	Wald	95th	99th	Wald	95th	99th	Wald	95th	99th
ENQ->TRA	3.091	8.991	11.112	4.258	9.767	13.109	5.087	9.965	13.299
ENQ->FDI	2.251	10.143	14.873	9.470*	10.071	15.387	23.691***	10.143	15.514
ENQ->GRE	6.220	9,678	22.627	51.588***	10.700	21.918	51.588***	10.700	22.627
ENQ->GRT	6.585	7.811	14.528	6.137	8.435	14.119	7.162*	8.456	14.528

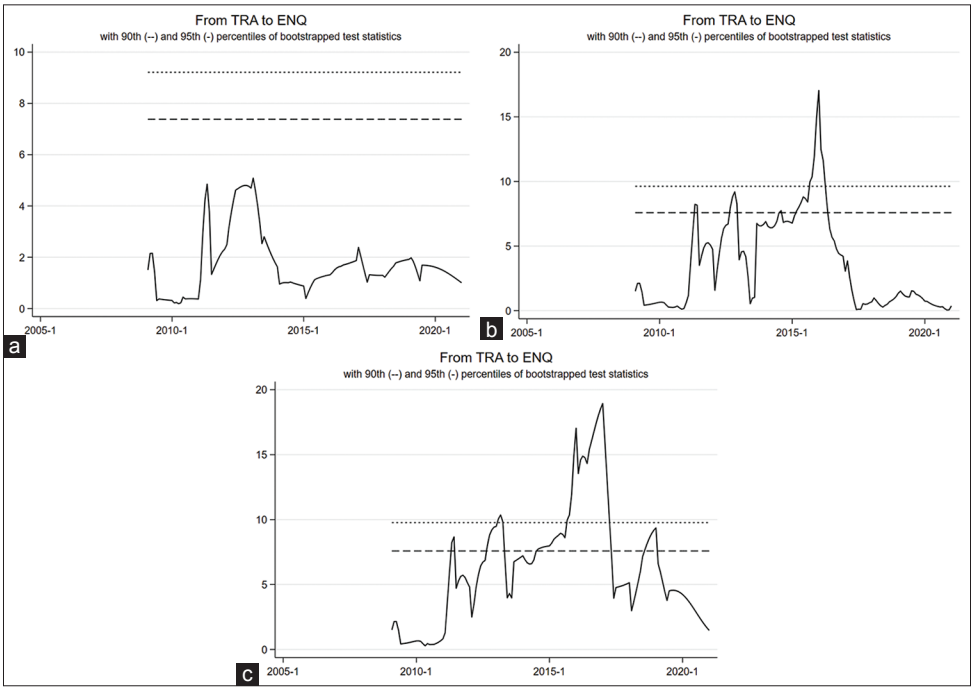
The table reports the robust Wald test statistics of Granger causality and the 95th and 99th quantiles of the empirical distributions of bootstrap statistics. ***, **, and *represent statistical significance at the 1%, 5%, and 10% level, respectively

Table 6: Wald test for Granger causality (dependable variable: ENQ)

Causality	Forward			Rolling			Recursive		
	Wald	95th	99th	Wald	95th	99th	Wald	95th	99th
TRA->ENQ	5.087	9.214	14.543	17.036**	9.628	18.153	18.941***	9.768	18.153
FDI->ENQ	1.984	11.623	16.543	7.810	11.623	18.687	7.824	11.745	18.980
GRE->ENQ	4.759	10.320	13.726	7.269	9.462	13.568	8.052	10.320	13.726
GRT->ENQ	6.602	9.017	13.909	10.748**	9.290	14.919	10.748**	9.290	15.136

The table reports the robust Wald test statistics of Granger causality and the 95th and 99th quantiles of the empirical distributions of bootstrap statistics. ***, **, and * represent statistical significance at the 1%, 5%, and 10% level, respectively

Figure 7: Time-varying causality from TRA to ENQ. (a) Forward recursive causality (b) Rolling causality (c) Recursive evolving causality



which indicates that ENQ did not cause Granger causality to FDI. For the recursive evolving causality, ENQ caused Granger causality to FDI just in short period from the end of 2011 to the beginning of 2013. The result shows that in the context of Vietnam, environmental factors appear to influence FDI inflows only during certain periods, rather than serving as a fundamental or long-term determinant. The result of the impact of ENQ to FDI agrees with the empirical results of Ali (2015); Fakhreldin and Elsawy (2018). While environmental regulations and sustainability concerns may affect foreign investors' decisions, particularly in periods of heightened global attention to green investment or when Vietnam implements stricter environmental policies, their overall impact remains situational. It can be explained that maybe other factors such as market size, labour costs, infrastructure quality… continue to play a more decisive and consistent role in shaping FDI trends over time.

From FDI to ENQ, Figure 9 below indicates that for the forward recursive causality, rolling causality and recursive evolving causality, the null hypothesis of no Granger causality cannot be rejected since the test statistic does not exceed the critical value statistic over the sample period. It means that FDI did not cause Granger causality to ENQ. This result is inconsistent with the research of Hamid (2016) and Fakhreldin and Elsawy (2018). In the case of Vietnam, the absence of a Granger causality from FDI to ENQ can be attributed to several structural and policy-related factors. It proves the trend that FDI inflows may have been largely concentrated in low-emission sectors such as electronics,

Figure 8: Time-varying causality from ENQ to FDI. (a) Forward recursive causality, (b) Rolling causality (c) Recursive evolving causality

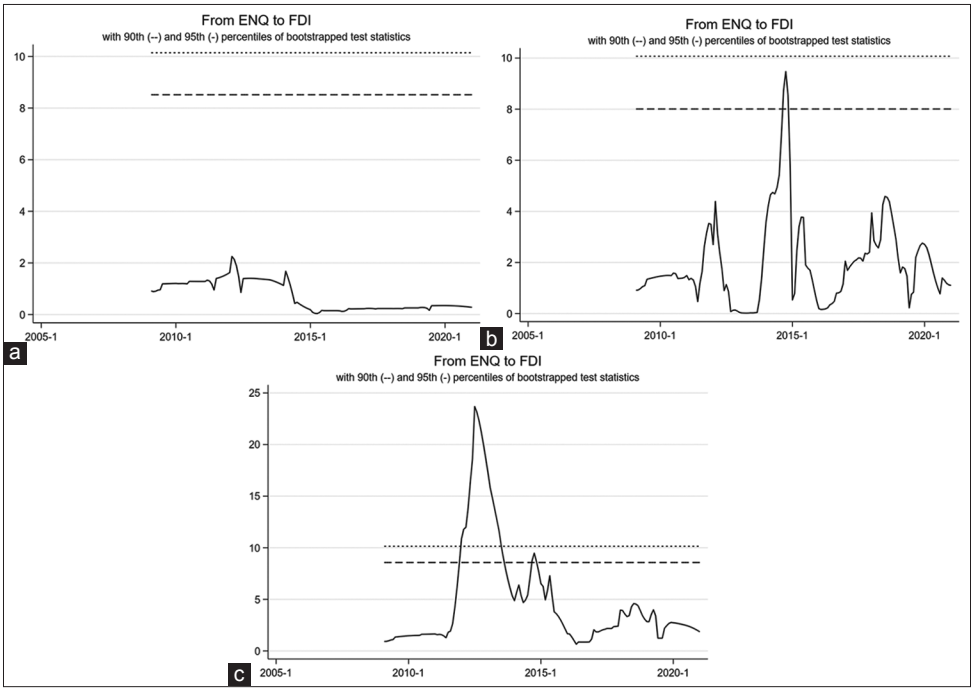
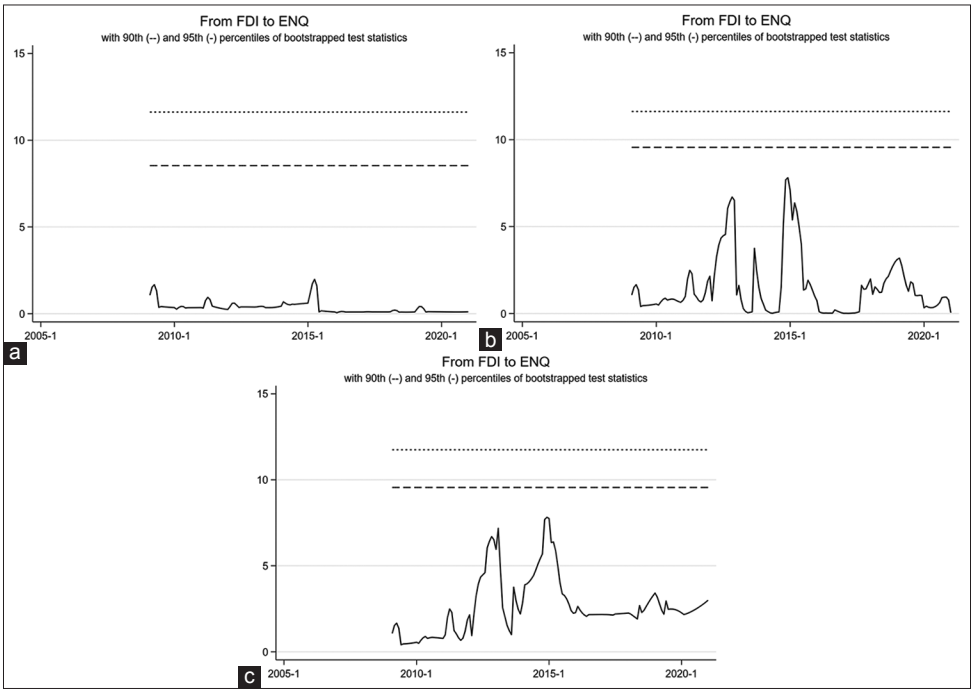


Figure 9: Time-varying causality from FDI to ENQ. (a) Forward recursive causality, (b) Rolling causality, (c) Recursive evolving causality



light manufacturing, and services, rather than in high-emission industries like thermal power or heavy manufacturing. In addition, many foreign investors, especially those from developed economies, bring with them advanced, cleaner technologies and management practices that may contribute to improved energy efficiency and lower emissions. Moreover, it can be explained that FDI has not played a dominant role in Vietnam's most carbon-intensive sectors, which is driven primarily maybe by the domestic businesses.

4.3.3. Time-varying causality between ENQ and GRE

From ENQ to GRE, Figure 10 shows that for the forward recursive causality, ENQ did not cause Granger causality to GRE. However, for rolling causality and recursive evolving causality, ENQ caused Granger causality to GRE in short period of from 2017 to 2019. This result is consistent with Caldera et al. (2024) who proved the causality throughout the short-term from renewable energy consumption to the CO_2 emission while it is different from Ben Jebli and Ben Youssef (2017) who identified the long-run

Figure 10: Time-varying causality from ENQ to GRE. (a) Forward recursive causality, (b) Rolling causality, (c) Recursive evolving causality

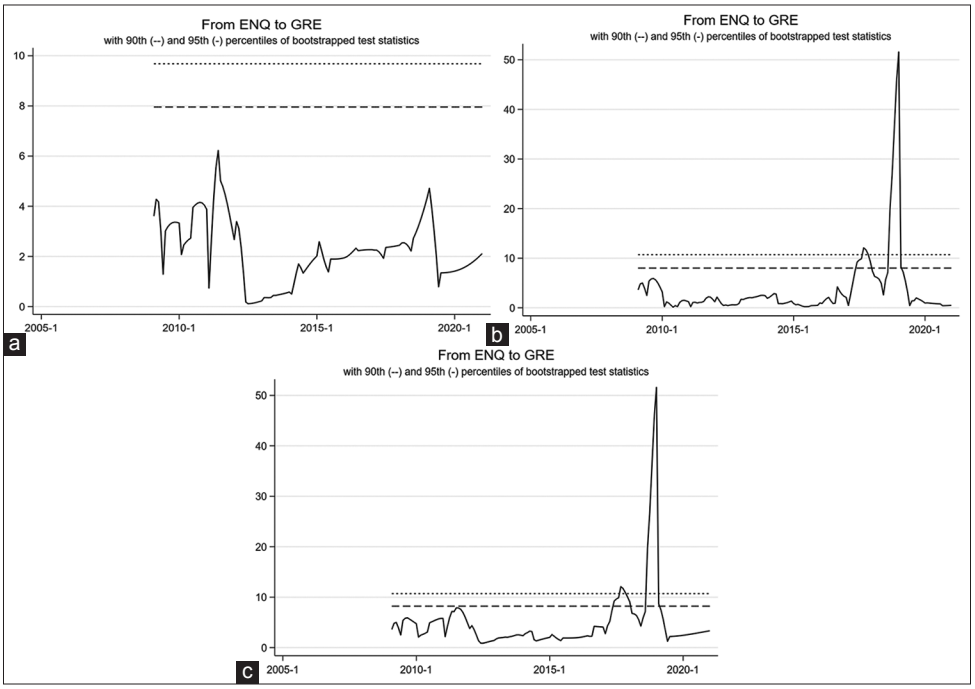
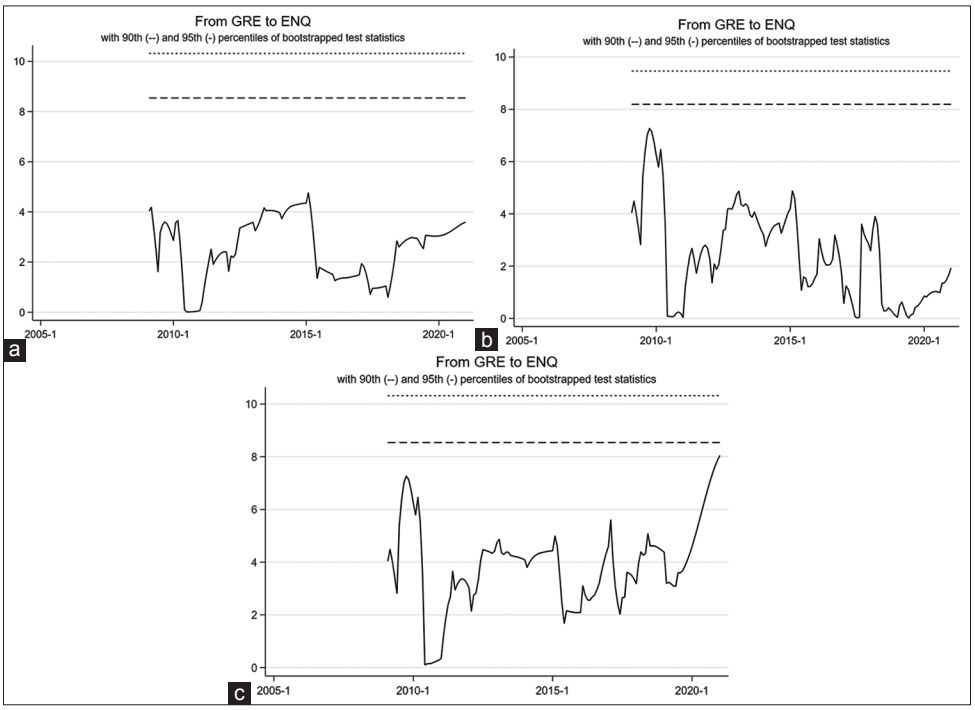


Figure 11: Time-varying causality from GRE to ENQ. (a) Forward recursive causality, (b) Rolling causality, (c) Recursive evolving causality



causality of renewable energy consumption which helps reduce CO_2 emissions. The empirical findings indicate that the Granger causality running from ENQ to GRE in Vietnam may lack long-term stability. However, there is emerging evidence of such a relationship during the more recent period of 2017-2019. This suggests a potential shift in the energy-environment dynamic, possibly driven by increased public and policy awareness of environmental degradation and the corresponding expansion of renewable energy initiatives.

From GRE to ENQ, Figure 11 shows that for the forward recursive causality, rolling causality and recursive evolving causality, GRE did not cause Granger causality to ENQ. The analysis results indicate that there is no strong or stable evidence of a Granger causal relationship from GRE to ENQ during the period 2008-2020. This may be attributed to the relatively small share of renewable energy in the national energy mix or the influence of other confounding factors on emissions. This result also aligns with Chen et al. (2022) who demonstrated that the negative

Figure 12: Time-varying causality from ENQ to GRT. (a) Forward recursive causality, (b) Rolling causality, (c) Recursive evolving causality

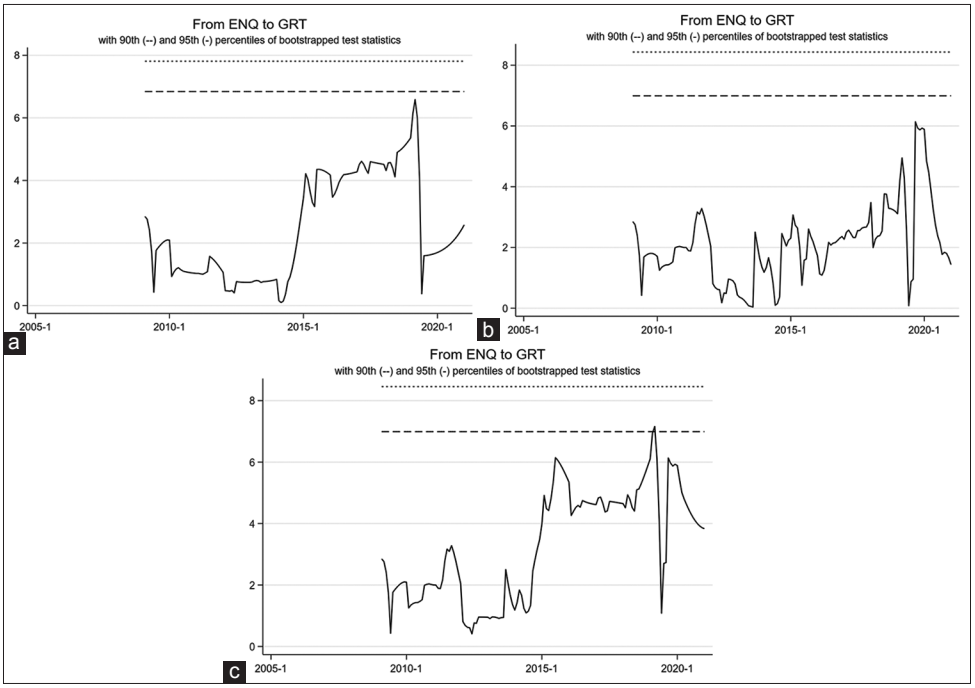
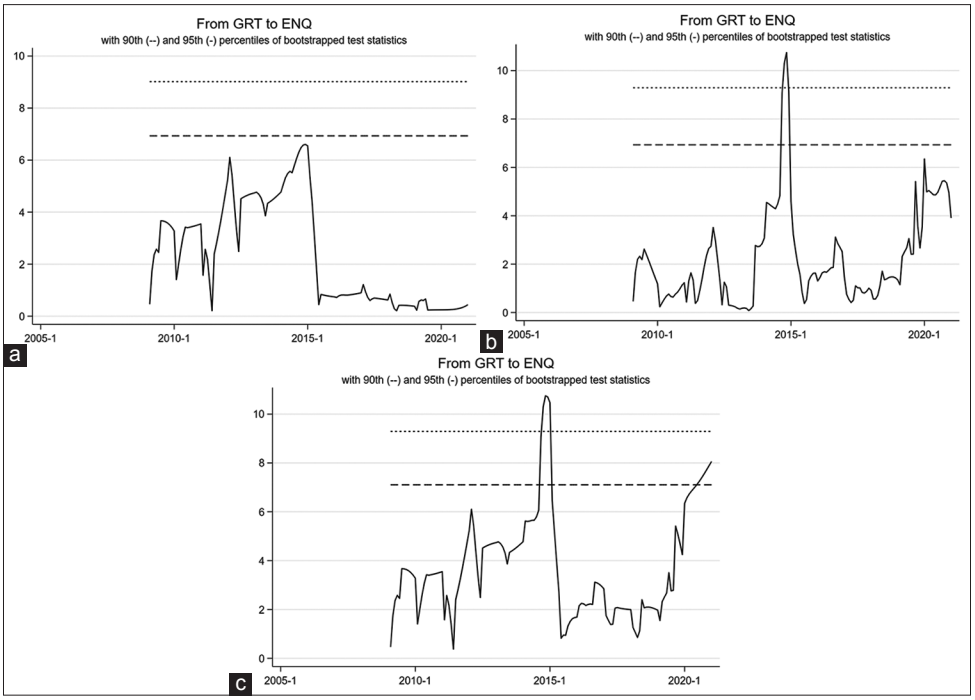


Figure 13: Time-varying causality from GRT to ENQ. (a) Forward recursive causality, (b) Rolling causality, (c) Recursive evolving causality



and significant impact of renewable energy consumption on CO_2 emissions only emerges once a country surpasses a certain threshold of renewable energy use per capita.

4.3.4. Time-varying causality between ENQ and GRT

From ENQ to GRT, Figure 12 demonstrates that for the forward recursive causality, rolling causality and recursive evolving causality, ENQ did not cause Granger causality to GRT. However, the trajectories of the test statistics across all three causality test approaches demonstrate an upward trend approaching the critical significance thresholds. This pattern suggests the gradual emergence of a causal relationship from ENQ to GRT in Vietnam. The discussion for this relationship is limited because most of research focuses on the effect of green tax to CO_2 emission.

From GRT to ENQ, Figure 13 demonstrates that for the forward recursive causality, GRT did not cause Granger causality to ENQ. For the rolling causality, there was a short period from 2014 to 2015 during which the test statistic exceeded the 95% critical value, indicating very strong evidence of causality from GRT to

ENQ. Outside of that period, the test statistic mostly remained below the significance thresholds, suggesting that the causal relationship was weak or non-existent for most of the time. For most of the period from 2005 to 2019, the test statistic remained below the significance thresholds, indicating no substantial causal relationship. However, starting in 2014, there was a sharp peak surpassing both the 90% and 95% thresholds, suggesting the existence of a strong short-term causal relationship. Notably, from late 2019 to 2020, the statistic again exceeded the 95% threshold, indicating a re-emergence of a clear causal relationship from GRT to ENQ. The period of strong causality (2014-2015) observed in both rolling causality and recursive evolving causality may be attributed to the sharp increase in Vietnam's environmental protection tax on fuels, especially gasoline, during 2012-2015. This followed the implementation of the environmental protection tax law, which came into effect in 2012. In late 2019, under the recursive evolving causality, a clear re-emergence of the causal relationship from GRT to ENQ was detected which can be explained that at that time, Vietnam officially committed to the Paris Agreement (COP21) and launched a national action plan for green growth. The result of the effect of GRT on ENQ just in short time is consistent with Chen et al. (2022) who demonstrated that environmental taxes reduce CO_2 emissions significantly when the share of GDP exceeds a critical threshold.

5. CONCLUSION AND RECOMMENDATIONS

This study employed time-varying Granger causality approaches, including the forward recursive, rolling window, and recursive evolving techniques to examine the causal relationships between environmental quality and key macroeconomic variables consisting of trade, FDI, green energy, and green tax in Vietnam over the period 2005-2020. The results reveal that the relationship between environmental quality and economic variables is unstable and context-dependent, reflecting the dynamic and complex nature of environment-economy interactions in Vietnam's transitional economy. Specifically, environmental quality was found not to Granger-cause trade over the entire period, suggesting that trade remains largely unadjusted to environmental factors. However, environmental quality showed short-term causal impacts on FDI and green energy, particularly during periods of policy shifts or increased international pressure for sustainable development. Conversely, trade and green tax significantly influenced environmental quality, indicating the dominance of economic activities and policy instruments over environmental quality, especially in the context of Vietnam's implementation of environmental tax reforms (2012) and COP21 commitments (2019).

Based on the above findings, some key policy implications are proposed as follows:

5.1. First, Policy Direction for Environmentally Sustainable FDI Attraction

A "pollution haven" strategy should be avoided and instead environmental standards to attract high-quality, clean-technology FDI should be enhanced. A stable and transparent environmental regulatory framework, including effective monitoring, reporting, and verification systems should be established. Moreover, targeted incentives should be provided to FDI projects aligned with green growth, renewable energy, and low-carbon technologies. FDI policy is essential for aligning with Vietnam's national emission reduction goals and international climate commitments, such as net-zero targets. Lastly, promoting environmental disclosure among FDI enterprises can create accountability and drive improved environmental performance through market and societal pressure.

5.2. Second, Policy Strategies to Leverage CO_2 Emissions for Accelerating Green Energy Transition

Emission pressures should be transformed into a strategic driver for energy transition by integrating emission data into energy planning. In addition, targeted incentives for green energy investments, particularly in high-emission industrial zones, can accelerate adoption. Furthermore, aligning national emission inventories with energy development plans can optimize green energy deployment. Lastly, raising awareness among businesses and society about the interdependence between emission reduction and clean energy development is critical to fostering long-term sustainability.

5.3. Third, Balance Trade Growth with Environmental Sustainability

Environmental standards for export-oriented industries should be strengthened, and enhancement of monitoring mechanisms should be taken. Simultaneously, promoting the import of green technologies which can improve energy efficiency in production. Moreover, integrating environmental requirements into the negotiation and implementation of free trade agreements (FTAs) is crucial to help domestic exporters comply with international environmental standards. Developing green logistics infrastructure and encouraging the use of low-emission transport modes also represent strategic directions. Finally, piloting carbon pricing mechanisms may be considered, such as carbon taxes or emissions trading systems, to gradually internalize environmental costs into the trade value chain, thereby fostering a more sustainable trade model in the long term.

5.4. Fourth, Developing Policies for Effective and Equitable Green Tax Implementation

Policy design should incorporate a gradual increase in tax rates to balance emission reduction incentives with economic stability. Furthermore, green tax should be integrated with supportive measures such as investment incentives, subsidies, or concessional loans for clean energy and technology transition. Differentiated tax schemes based on industry sector and enterprise size can help mitigate adverse effects on vulnerable sectors and safeguard employment. In addition, transparency and public disclosure regarding green tax implementation and its environmental impacts are essential to enhance social awareness and stakeholder engagement. Finally, establishing robust monitoring and evaluation systems is critical to regularly assess the policy's effectiveness and to enable timely adjustments, ensuring both environmental and social equity objectives are met.

Overall, this study contributes to the literature by providing

empirical evidence on the nexus between trade, FDI, green energy, green tax, and environmental quality, using time-varying Granger causality. It underscores the significance of tailored policies for trade, FDI, green energy, green tax that exerts a causal effect on environmental quality. Future research could expand by incorporating additional factors such as institutional quality and environmental policy, or by comparing the nexus in Vietnam with that of other countries.

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