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Drivers of Green Growth and Carbon Emissions in Vietnam: A Wavelet and Quantile-on-Quantile Examination

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ABSTRACT

This paper examines the dynamic interrelationships between renewable energy use, environmental protection tax, and human capital quality in driving green growth and carbon emissions in Vietnam from 1995 to 2024. A novel Green Growth Index is constructed using FinBERT, a financial domain natural language processing model, to capture policy-driven progress toward sustainability. By integrating wavelet analysis and quantile-on-quantile regression, the study disentangles time-frequency dynamics and quantile-dependent effects. The results indicate that renewable energy and environmental taxes contribute to reducing CO_2 emissions, while human capital significantly enhances green growth but also increases emissions. The study highlights the dynamic and asymmetric relationships among these variables and provides policy implications for achieving Vietnam's green transition.

Keywords: Green Growth, Renewable Energy, Environmental Protection Tax, Quantile-on-Quantile Regression, Wavelet Analysis
JEL Classifications: Q56, Q21, O44

1. INTRODUCTION

The rapid growth over the past three decades has become a "double-edged sword" for Vietnam, as the intense process of industrialization and urbanization has led to severe environmental consequences, including resource degradation, air and water pollution, and particularly a surge in greenhouse gas emissions. Faced with these challenges, Vietnam has demonstrated a strong strategic shift towards sustainable development. The commitment to achieving net-zero emissions by 2050 at the COP26 Conference and the issuance of the "National Strategy on Green Growth for the 2021-2030 period, with a vision to 2050" have set an ambitious roadmap, requiring a profound restructuring of the economy (Nguyen et al., 2023).

This context creates a core tension that this study aims to address: How to better understand the effectiveness of key policy levers, including promoting renewable energy, applying environmental taxes, and developing human capital, in steering Vietnam's economy towards the dual, and sometimes conflicting, objectives of green growth and decarbonization (Nguyen et al., 2023).

Previous empirical studies on green growth and carbon emissions in Vietnam, despite their contributions, have largely relied on traditional econometric models such as ARDL or VECM (Le and Nguyen, 2017; Thanh et al., 2024). These methods inherently assume that the relationships between variables are linear and stable over time. This assumption may not fully capture the dynamics of a highly open economy that has undergone significant structural changes like Vietnam. They cannot capture non-linear impacts, changes in relationships across different economic cycles, or differences in policy effectiveness under varying socio-economic conditions (Hinson, 2019).

This study proposes a method for constructing a green growth index (GG) for Vietnam. By analyzing a large dataset of policy documents, economic reports, and media news related to 72 green growth indices from the Ministry of Planning and Investment of Vietnam, we apply the FinBERT model, a natural language processing (NLP) model trained explicitly for the economic and financial sector (Araci, 2019). This creates a dynamic index of green growth that reflects the intensity and direction of green development efforts and results over time.

Regarding the research method, we use three wavelet transforms and quantile-on-quantile regression (QQR): Wavelet analysis is a non-stationary time series analysis tool that enables the evaluation of relationships between variables in time-frequency domains, thereby determining the effects that occur in short-term, medium-term, and long-term cycles, as well as the causal relationships between variables (Aguiar-Conraria and Soares, 2010); The QQR method of Sim and Zhou (2015) facilitates the estimation of the impact of each quantile of the independent variable on each quantile of the dependent variable. This combination allows for a more detailed perspective and may help clarify that the policy has a significant impact. This approach may provide additional insights that offer much more practical policy implications than traditional methods.

2. THEORETICAL FRAMEWORK AND LITERATURE REVIEW

2.1. Green Growth and Low Carbon Emissions

The concept of green growth, although not unfamiliar, is approached from many different perspectives. The OECD defines green growth as promoting economic growth and development while ensuring that natural resources continue to provide the environmental services on which our well-being depends. Meanwhile, the World Bank states that green growth must be associated with the use of clean and efficient natural resources, minimizing negative impacts on the environment, taking natural hazards into account, and preventing disasters. Although these organizations offer different definitions, they all emphasize that green growth is synonymous with sustainable economic development, prioritizing environmental protection, efficient resource use, and minimizing negative impacts on people and ecosystems. The key components of green growth include sustainable production and consumption; greening businesses and markets—where current market prices often do not fully reflect the costs of processing inputs (e.g., natural resources) and outputs (e.g., waste, wastewater, and emissions); building sustainable infrastructure; taxing polluting emissions; and investing in natural capital (Toman, 2012).

Overall, green growth aims to decouple economic development from environmental degradation through a transition to clean technologies and the development of renewable energy. Furthermore, green growth highlights the importance of reducing greenhouse gas emissions, protecting biodiversity, and building climate-resilient economies.

The low-carbon economy is currently the widely accepted development model. The UK government first proposed this concept in its Energy White Paper as achieving more economic output by consuming fewer natural resources and generating less environmental pollution (Yuan et al., 2011). Cranston et al. (2010) concluded that a low-carbon economy in the 21st century signifies a balance and harmony between population growth, economic development, and environmental protection. American researchers Hughes and Chandler highlighted that the core of a low-carbon economy is maximizing CO_2 emission reductions through economic licensing mechanisms. A renewable energy and energy efficiency partnership report (REEEP) stated that a low-carbon economy is a development path aimed at achieving global economic growth while limiting increasing energy demand, promoting low-carbon product production, and simultaneously providing sufficient safe energy sources (Parthan et al., 2010). Common characteristics of a low-carbon economy include low energy consumption, low pollution, and low emissions. It cannot advance without innovations in the energy sector. Ultimately, the goal of a low-carbon economy is to achieve sustainable development.

2.2. Renewable Energy (ERW)

The relationship between renewable energy, green growth, and carbon emissions is a topic of widespread debate. Previous studies have demonstrated that renewable energy is a key component of sustainable development, having a positive impact on economic growth and a mitigating effect on CO_2 emissions (Khan and Ulucak, 2020; Khan et al., 2022; Suki et al., 2022). However, some other studies present an opposing view, suggesting that during the initial transition stage, renewable energy investment often incurs high costs and is unstable, which can temporarily hinder economic growth (Xuan et al., 2023). Thus, the impact of renewable energy on economic growth may not be a simple linear relationship, but rather depends on several factors, such as the stage of development, financial structure, and the supporting policy framework.

Hypothesis 1: Renewable energy consumption has a negative effect on CO_2 emissions, but may have a heterogeneous effect on green growth.

2.3. Environmental Protection Tax (ETX)

In theory, the environmental protection tax is designed to increase tax revenue and reduce pollution (Sterner, 2007). Some previous empirical studies have confirmed the inverse relationship between environmental tax and CO_2 emissions (Dinga et al., 2022; Miller and Vela, 2013). However, the effectiveness of this tax instrument depends to some extent on the provisions in the tax policy itself. Research by Wier et al. 2005 suggests that if the tax rate is too low or the demand for taxed goods is inelastic, the impact on reducing emissions will be very limited (Wier et al., 2005). The environmental protection tax in Vietnam appears to be having a similar effect. The state imposes an environmental protection tax mainly on petroleum products, including gasoline, oil, plastic bags, etc. It contributes to state tax revenue but is not yet an effective tool for regulating environmental behavior (Ngan, 2023; Samuel, 2023).

Hypothesis 2: Environmental protection tax reduces CO_2 emissions and has a positive impact on green growth.

2.4. Human Capital Quality (HDI)

Human capital quality plays a dual role in the sustainable development process. On one hand, a highly educated and skilled workforce is a driver for green innovation, enhances resource use efficiency, and promotes the adoption of clean technologies (Lan et al., 2012). On the other hand, the process of human development, which includes increases in income and living standards, often goes hand in hand with increased energy consumption and emissions, creating a "development paradox" (Khan, 2020). Many studies have recorded a positive comovement between HDI and CO_2 emissions in developing countries, suggesting that these nations have not yet reached the turning point of the Environmental Kuznets Curve (Ahmed et al., 2020).

Hypothesis 3: Human capital quality has a positive impact on green growth but exhibits a paradoxical positive relationship with CO_2 emissions.

3. DATA AND RESEARCH METHODOLOGY

This study uses annual time-series data for Vietnam from 1995 to 2024. The data are compiled from reputable international and domestic sources. Detailed variable definition and variable measurements are provided in Table 1.

To overcome the limitations of traditional proxy variables, this study pioneers the application of the FinBERT natural language processing model to construct the GG index. FinBERT is a variant of the BERT model, specifically fine-tuned on a large corpus of financial and economic data, giving it a deep understanding of context and sentiment in specialized texts (Arner et al., 2015; Malo et al., 2014).

The index construction process includes the following steps: (1) Collecting a large corpus of texts, including annual government reports, national strategies, public investment plans, and legal documents related to the 72 indicators in Circular No. 10/2023/TT-BKHDT of the Ministry of Planning and Investment of Vietnam, Regulating the set of statistical indicators for green growth. (2) Each document is segmented into sentences or paragraphs. (3) Using the pre-trained FinBERT model to classify the sentiment of each text segment into three labels: positive, negative, or neutral towards green growth objectives. (4) A sentiment score is calculated for each document based on the probabilities of these labels, using the common formula: SentimentScore = P(positive) - P(negative) (Qiao et al., 2023). (5) Finally, the annual sentiment scores are aggregated and normalized, weighted based on the four main pillars of the national green growth strategy, to form the final GG index.

The research method used in this paper is a combination of tri-variate Wavelet analysis and quantile-on-quantile regression (QQR). Wavelet analysis is a mathematical tool that allows for the analysis of non-stationary time series in both the time and frequency domains simultaneously, unlike traditional Fourier analysis, which only operates in the frequency domain (Ramsey and James, 2002; Gençay et al., 2002). This technique is particularly suitable for studying macroeconomic relationships, which often have cycles and shocks that vary over time (Aguiar-Conraria and Soares, 2010). This study uses three main tools of Wavelet analysis:

3.1. Continuous Wavelet Transform (CWT)

CWT generates a two-dimensional map showing the volatility intensity of a single time series at each point in time and at each frequency/cycle (Torrence and Compo, 1998). The continuous wavelet function is described by the following formula:

$$W_x(S) = \int_{-\infty}^{\infty} x(t)\frac{1}{\sqrt{S}}\psi^*(\frac{t}{S})$$

3.2. Cross Wavelet Transform (XWT)

XWT extends CWT to analyze 2 time series, identifying time-frequency regions where they have high "common power," meaning they co-vary strongly (Grinsted et al., 2004). This helps detect periods of co-movement between two variables. The formula for determining the cross wavelet is illustrated as follows:

$$W_n^{XY}(u,s) = W_n^X(u,s) \times W_n^{Y*}(u,s)$$

Where: u denotes the position, s is the scale corresponding to each frequency domain, and * denotes the complex conjugate.

3.3. Wavelet Coherence (WTC)

WTC measures the local correlation between two series, similar to a rolling correlation coefficient but calculated in both the time and frequency domains (Grinsted et al., 2004). WTC can detect linkages even when the common power is low. More importantly, WTC uses phase arrows to indicate the lead-lag causal relationship between the two variables. The function representing the wavelet coherence between two variables X and Y is described as follows:

$$R_n^2(u,s) = \frac{S(s^{-1}|W_n^{XY}(u,s)|^2}{S(s^{-1}|W_X(u,s)|^2 \; S(s^{-1}|W_Y(u,s)|^2}$$

Additionally, the quantile-on-quantile regression (QQR) method, developed by Sim and Zhou (2015), is a powerful extension of traditional quantile regression. While standard quantile regression only estimates the impact of an independent variable on different quantiles of the dependent variable, QQR allows for the estimation of the impact of each quantile of the independent variable on each quantile of the dependent variable. This creates a three-dimensional, detailed picture of the relationship, allowing for the detection of complex non-linear and asymmetric effects. The QQR model is represented as:

$$Y_t = \beta^{\theta}(X_t) + u_t^{\theta}$$

Where: Yt is the dependent variable and Xt is the independent variable at time t, θ is the θ-th quantile of the distribution of X. Additionally, u_t^θ represents the error term and β_θ is the regression coefficient. By localizing this function around a τ-th quantile of Xt, the model can be estimated locally, allowing the coefficient β to vary with both θ and τ.

Finally, to illustrate the impact of the observed factors on green growth and low carbon emissions, the equation is represented as follows:

$$Min_{b_0,b_1}\sum_{i=1}^{n} p_{\theta}[Y_t - b_0 - b_1(\hat{X}_t - \hat{X}^{\tau}]K(\frac{F_n(\hat{X}_t)-\tau}{h})$$

Table 1: Definition, measurement, and data sources of variables

Variable name	Symbol	Description	Source
Green growth	GG	A composite index constructed using the FinBERT model based on 72 indicators from Circular 10/2023/TT-BKHĐT	The author's calculation
Carbon emission	CO_2	Per capita CO_2 emissions (tonnes/person), excluding LULUCF	OECD
Environmental protection tax	ETX	Total revenue from environmental protection tax as a percentage of GDP (%).	GSO
Renewable energy	ERW	Share of renewable energy in total final energy consumption.	OECD
Human capital	HDI	Human Development index (HDI) on a scale of 0-1.	WDI

Source: Author's synthesis

Table 2: Descriptive statistics

Variable	Mean	Standard	Min	Max	Skewness	Kurtosis	Jarque-Bera	P-value
GG	13.14	2.84	7.45	18.8	0.01	−0.62	0.62	0.73
CO_2	1.75	1.02	0.48	3.72	0.64	−0.75	2.61	0.27
ETX	0.43	0.26	0.00	0.90	0.11	−0.78	0.92	0.63
ERW	40.75	13.91	18.90	64.9	0.21	−1.17	1.86	0.39
HDI	0.64	0.05	0.54	0.71	−0.57	−0.85	2.41	0.30

Source: Authors' estimates

Where: $p_\theta(u)$ is the quantile check function $p_\theta(u) = u(\theta - I(u<0))$ and K(.) is a kernel function. The main advantage of QQR is its robustness to outliers and its lack of strict assumptions about the distribution of errors, making it ideal for analyzing macroeconomic data that often contains significant volatility and shocks.

4. RESULTS AND DISCUSSION

4.1. Descriptive Statistics and Preliminary Tests

After being calculated and fully normalized, the data was subjected to descriptive analysis and correlation matrix analysis between variables using programming algorithms in the Python language on the Google Colab platform. The results of the descriptive statistics for the variables are detailed in Table 2.

The descriptive statistics show significant variation in the variables during the study period. The indicator representing comprehensive green growth in Vietnam has an average value of 13.15 with a relatively low standard deviation of 2.84, indicating that Vietnam's green growth has been quite stable, without drastic or strong changes in specific periods. The level of carbon emissions in Vietnam also shows an annual change with a standard deviation of 1.02; although it has slightly decreased in recent years, the trend of change remains small. Notably, the Human Development Index shows small changes, with a standard deviation of only about 0.05. During the period 1995-2023, the index measuring comprehensive human development in Vietnam ranged from 0.54 to 0.71, showing a small, indistinct change due to the social context of wealth disparity, income inequality, and quality of life differences between rural and urban areas.

The ADF unit root test results show that most series are non-stationary at their levels and become stationary at the first difference (Table 3), while the Johansen cointegration test confirms the existence of a long-run equilibrium relationship between the variables (Table 4). These characteristics affirm the suitability of applying Wavelet and QQR analysis methods.

Table 3: Stationarity test

Variable name	Order of differencing for stationarity order of integration	Test statistic	Critical values 1pct	5pct	10pct
GG	1	−3.5679**	−3.58	−2.93	−2.60
CO_2	1	−3.3563**	−3.58	−2.93	−2.60
ERW	1	−3.6809***	−3.58	−2.93	−2.60
ETX	1	−4.1866***	−3.58	−2.93	−2.60
HDI	0	−2.7551*	−3.58	−2.93	−2.60

(*) denotes significance at the 10% level. (**) denotes significance at the 5% level. (***) denotes significance at the 1% level

Table 4: Johansen cointegration test

Pair of variables	Lag order	Trace statistic	Interpretation
ETX→GG	1	4.0178	No cointegration relationship
GG→ETX	1	4.0178	No cointegration relationship
ERW→GG	1	6.6795	No cointegration relationship
GG→ERW	1	6.6795	No cointegration relationship
HDI→GG	2	11.4306**	Cointegration relationship exists (5%)
GG→HDI	2	11.4306**	Cointegration relationship exists (5%)
ETX→CO_2	4	7.2895	No cointegration relationship
CO_2→ETX	4	7.2895	No cointegration relationship
ERW→CO_2	5	10.2927**	Cointegration relationship exists (5%)
CO_2→ERW	5	10.2927**	Cointegration relationship exists (5%)
HDI→CO_2	5	6.179	No cointegration relationship
CO_2→HDI	5	6.179	No cointegration relationship

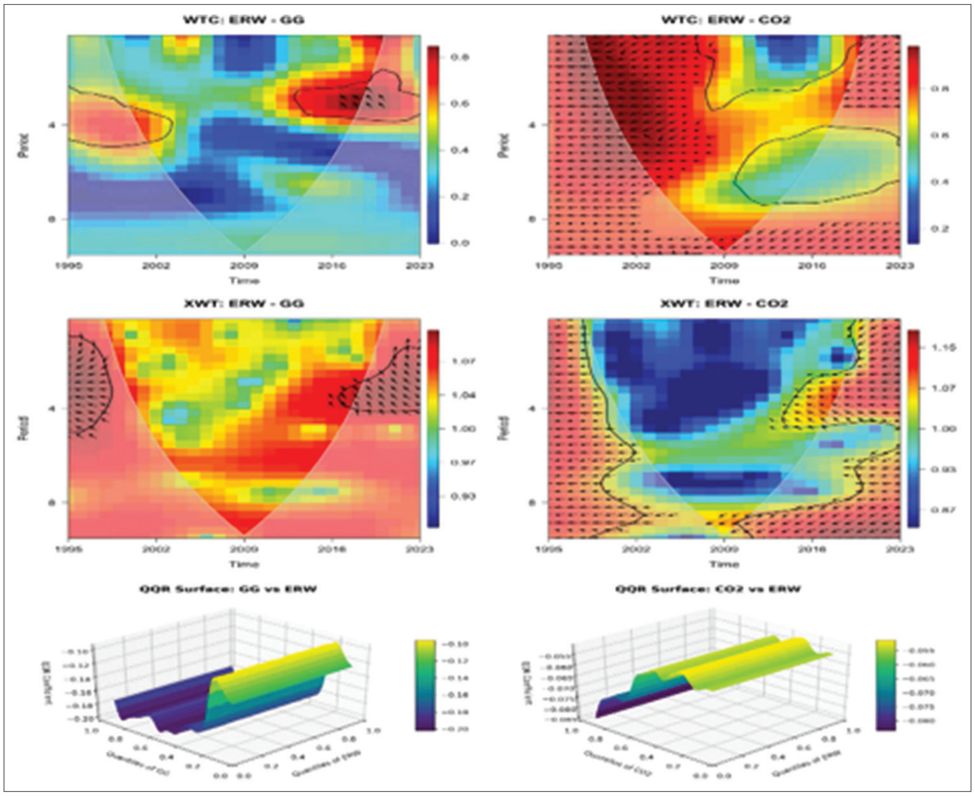
(*) denotes significance at the 10% level. (**) denotes significance at the 5% level. (***) denotes significance at the 1% level

4.2. Analysis of the Impact of Factors on Green Growth and Low Carbon Emissions

4.2.1. Impact of renewable energy (ERW)

Figure 1 shows the results of the analysis of the impact of ERW on GG and CO_2. Overall, the wavelet analysis results show an inverse phase relationship between ERW and GG and a lagging effect of ERW on GG. The QQR regression yields similar results.

Figure 1: Results of wavelet analysis and quantile-on-quantile regression regression of the impact of ERW on green growth and CO_2



Source: Authors' estimates

Specifically, at low quantiles of GG (τ_GG ≈ 0.1-0.3) and medium quantiles of ERW (τ_ERW ≈ 0.4-0.6), β drops to around −0.20, indicating that during periods of weak green growth, the energy transition requires high conversion costs, temporarily hindering the "greening" pace of the economy. At high quantiles of both GG and ERW (τ_GG, τ_ERW ≈ 0.7-1.0), β is more modest, around −0.12 to −0.10. This implies that when the economy has reached a certain threshold of green growth and the proportion of renewable energy is already high, adding more renewable energy creates a more positive "synergistic" impact, reducing the hindrance to green growth. This result contradicts the initially proposed research hypothesis and is similar to the findings of Banday and Aneja (2020), explained by differences in institutional culture and the level of renewable energy development. This result adds meaning to the research findings of Sovacool and Drupady (2012), who argued that the initial phase of importing large-scale renewable energy technology is often associated with high investment costs and sub-optimal efficiency, which can temporarily hinder green growth in a country.

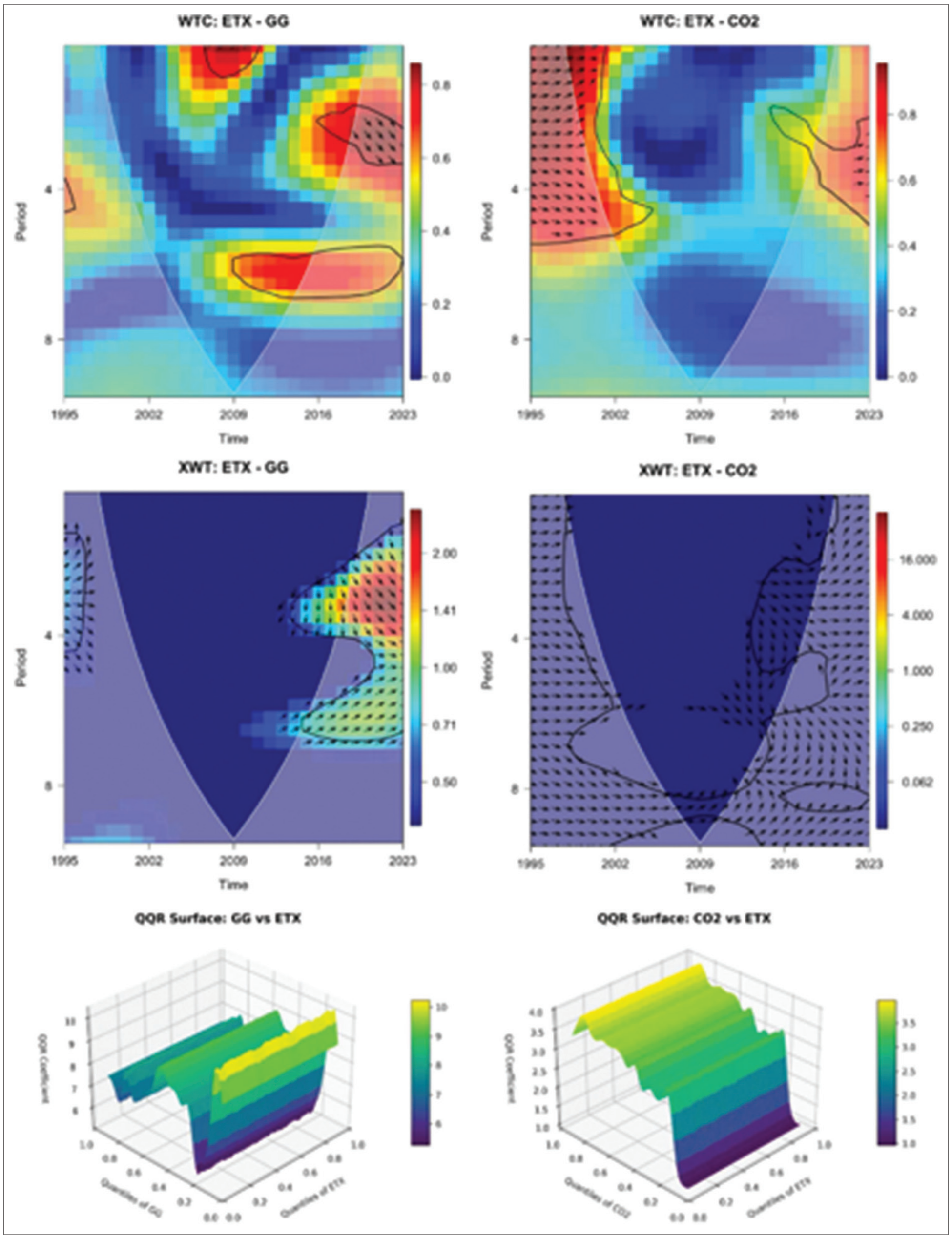
The Wavelet analysis for the ERW-CO_2 pair shows a very strong and statistically significant negative coherence region in the long-run cycle (4-8 years), particularly evident after 2016. The phase arrows predominantly point to the left, indicating that as renewable energy consumption increases, carbon emissions tend to decrease. This reflects the positive impact of the "policy push" from the FIT price mechanism, which created a wave of investment in solar and wind power, starting to change Vietnam's power source structure.

The QQR regression results further clarify the heterogeneity of this impact. The 3D plot shows that the regression coefficient between ERW and CO_2 is always negative, but its absolute value is largest—meaning the emission reduction effect is strongest—when ERW is at low to medium quantiles (0.2-0.5) and CO_2 is at high quantiles (0.7-0.9). This finding suggests a potential policy implication that renewable energy can be an effective "initial intervention" tool in addressing high-emission scenarios. When an economy is heavily dependent on fossil fuels, renewable energy replaces the dirtiest and least efficient power sources, yielding a significant marginal reduction in emissions. As the power system becomes cleaner, the marginal effectiveness of adding more renewable energy tends to diminish. This result aligns with the initial research hypothesis and the studies of Khan et al. (2022), Suki et al. (2022), who argue that renewable energy is a factor that reduces carbon emissions. However, the research also shows that the reduction efficiency is not uniform, similar to the conclusions in the study of Polemis and Tsionas (2023), who warned that renewable energy "by itself" is not sufficient and must be accompanied by policies to reduce coal use to see the most significant impact.

4.2.2. Impact of environmental protection tax (ETX)

We observe that ETX has a strong influence on GG, especially in the medium and long term (Figure 2). The correlation between ETX and GG shows the highest positive correlation in the 2015-2021 period in the 4-6 year cycle, with arrows pointing from left to right and downwards. This indicates a positive relationship between ETX and GG, with ETX playing a leading role in driving green growth. Notably, this period has a high coherence region

Figure 2: Results of wavelet analysis and quantile-on-quantile regression regression of the impact of ETX on green growth and CO_2



Source: Authors' estimates

(>0.6) with similar significance in the statistically significant area on the WTC plot, which is consistent with the XWT map. This is because from 2015 onwards, the link between environmental protection tax and green growth became more pronounced, with the tax possibly being a key trigger for greening the economy. The 2015-2021 period can be seen as a turning point when the environmental protection tax policy began to play a role in directing green growth, although not yet fully distinct. This period witnessed a sharp increase in the gasoline tax to the ceiling of 4,000 VND/liter from 2019 (under the 2010 Law on Environmental Protection Tax). The government's push to "tax to guide consumption" (for gasoline, oil, coal) had a significant impact on green growth because after the tax rate increased sharply and stabilized, the government simultaneously promoted financial instruments to support green growth, such as the issuance of green bonds (by EVNFinance in 2022) and the 2021-2030 green growth strategy (Decision No. 1658/QD-TTg of the Prime Minister of Vietnam: Approving the National Strategy on Green Growth for the 2021-2030 period, with a vision to 2050). This result is consistent with the author's research hypothesis and previous studies by Kaygusuz et al. (2007) and Yin et al. (2015).

The Wavelet analysis for the ETX-CO_2 pair yields a finding that contradicts theoretical expectations. In the long-run cycle, the WTC shows a positive coherence, meaning that periods with high environmental tax revenue coincide with periods of high emissions. This suggests that the environmental protection tax in Vietnam, which is primarily a tax on petroleum products, has not acted as an effective deterrent. Instead, it has functioned as a source of state budget revenue that increases with the scale of economic activity and energy consumption, thus moving in the same direction as emissions.

The 3D diagram shows that the negative impact coefficient of ETX on CO_2 is statistically significant in a narrow range. Environmental protection tax will have an impact on changing CO_2 emission behavior when the tax rate creates a certain economic pressure, polluter pays. At most other tax rates and emission levels, the impact of the tax is insignificant or even positive. This finding provides evidence that the current structure and levels of environmental protection tax in Vietnam are not really effective in achieving the goal of large-scale emission reduction. This finding is consistent with the research of Samuel (2023) and Kaygusuz (2007), who found that environmental tax only produces significant emission reductions when applied at high levels.

4.2.3. Impact of human capital quality (HDI)

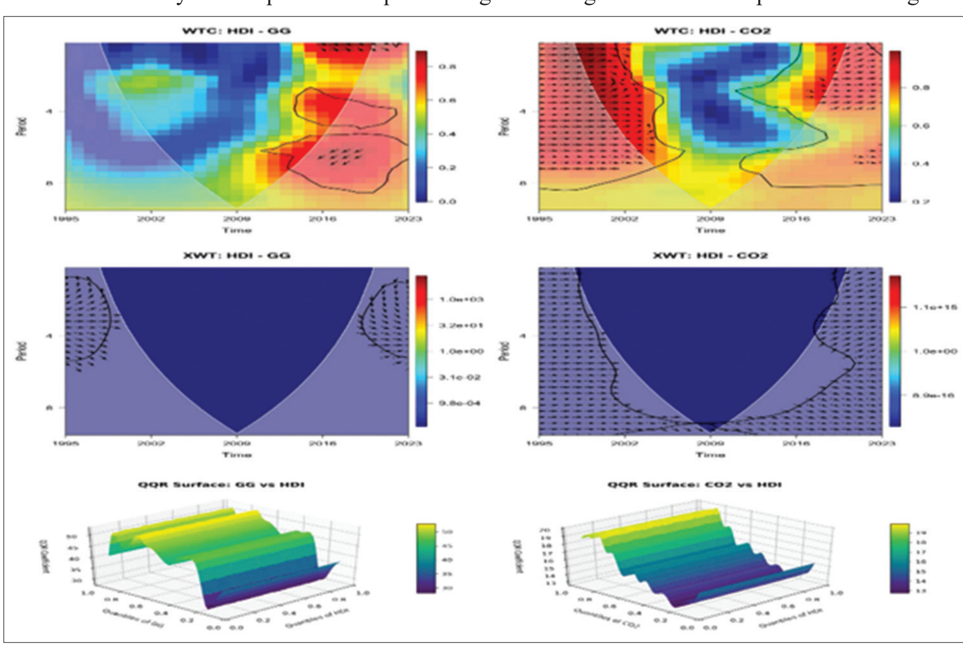
The results show that the relationship between HDI and both GG and CO_2 is mainly observed in the long and medium term; in the short term, the correlation between these factors is relatively weak (Figure 3). For the HDI-GG relationship, the correlation on the XWT plot is only evident in the medium-term in the statistically significant region. The in-phase arrows tend to point downwards in the long run, indicating a leading relationship from HDI to GG, but this only appears at the edge of the cone of influence (COI)—specifically, before 1998 and after 2020. However, the period between 2000 and 2020 is almost devoid of statistically significant data, suggesting a weak link during this phase. This corresponds to the period when Vietnam increased investment in education, healthcare, and national-level green growth policies such as the 2012 National Green Growth Strategy, the 2014 Action Plan, and the new 2021 Strategy. Growth in human capital, particularly investments in education, healthcare, and social equality—the main components of HDI—is a fundamental condition for activating green growth.

The research findings regarding the role of human capital (HDI) in green growth (GG) are consistent with the research of Lucas (1988), who emphasized the role of the human factor in technological innovation, which aligns with the strong positive β at high τ. However, this result also validates the study by Hickel (2020), who warned that if HDI is improved without being linked to environmental policies, GG will grow slowly.

Regarding the relationship between HDI and CO_2, there is an strong, stable, and statistically significant positive coherence across the entire long-run frequency band and for most of the study period. The phase arrows almost always point to the right, confirming that improvements in human development—in terms of income, education, and health in Vietnam have occurred in parallel with an increase in carbon emissions. This is an evidence of a resource-intensive development model, where higher living standards are traded for a larger carbon footprint.

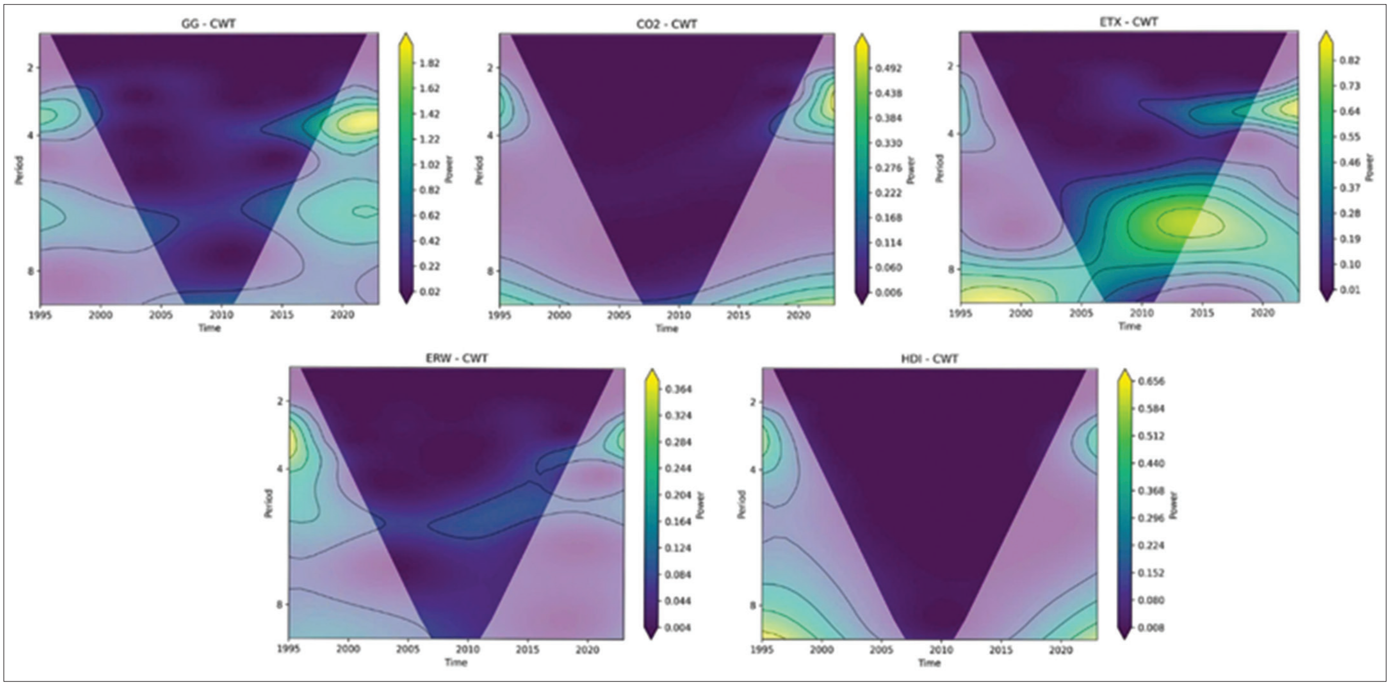
The QQR results reinforce this finding. The impact coefficient of HDI on CO_2 is positive across the entire distributional surface. Notably, this coefficient reaches its maximum value when both HDI and CO_2 are at high quantiles. This suggests that the link between development and emissions becomes even tighter at the highest stages of the economy's development. This is entirely plausible, as an increase in HDI accompanied by a rise in CO_2 emissions is an understandable reality in a traditional development model. This research result is fully consistent with the research hypothesis of the research team and the findings of Ahmed et al. (2020) and Hickel (2020), which show that the Environmental Kuznets Curve is still in phase (increasing HDI increases CO_2), perfectly matching the positive and large β at high τ. Only when HDI crosses

Figure 3: Results of wavelet analysis and quantile-on-quantile regression regression of the impact of HDI on green growth and CO_2



Source: Authors' estimates

Figure 4: Continuous wavelet transform results for variables



a sustainability threshold ($\tau > 0.9$) and green policies are sufficiently strong can we expect β' to turn negative, a state that Vietnam has not yet achieved during the period of this study. Continuous Wavelet Transform results for variables are presented in Figure 4.

5. CONCLUSION AND RECOMMENDATIONS

This study contributes to the existing evidence on the dynamics of green growth and carbon emissions in Vietnam. Based on the data and research methods presented above, the main results show that the impact of dependent variables on green growth is not fixed; this relationship is governed by the time cycle and specific socio-economic conditions. The results show that renewable energy is a tool for reducing emissions in the long term, particularly in the early stages of the transition; environmental protection taxes may be less effective if not applied at relatively high tax rates; human development is a necessary condition for green growth in the long term.

From the empirical results, the study proposes several recommendations to promote green growth in Vietnam, as follows.

First, renewable energy remains a cornerstone of long-term green growth. Therefore, the State needs to have policies to support and promote the production and consumption of environmentally friendly renewable energy. In addition to support mechanisms such as the feed-in tariff (FIT) policy, in which the Government commits to purchasing electricity from renewable energy projects (such as solar power, wind power) at preferential prices and guaranteed for many years, it is necessary to prioritize investment in modernizing the power grid to increase the ability to absorb renewable energy. Avoid producing but having difficulty transmitting electricity to the national grid.

Second, for the current environmental tax policy, the State can consider shifting from taxing products such as gasoline, oil, etc. to taxing based on the carbon content of fuel and the emission levels produced by high-emission industries. The tax rate needs to be adjusted significantly to reach the "effective threshold" determined through analysis, especially for large-emission enterprises. Revenue from environmental tax should be reused to support low-income households and finance green transformation projects.

Third, HDI is a driving force for green growth, but the most obvious impact only appears at high HDI levels or in the long term. The current HDI does not automatically create green growth, because Vietnam's human development process is still accompanied by increased emissions. Thus, breaking the negative link between HDI and CO_2 requires integrating sustainability, circular economy, and climate change into education systems at all levels. Training and reskilling programs to prepare the workforce for environmentally-driven manufacturing and business sectors. Investment in human capital should go hand in hand with investment in clean technology and sustainable infrastructure to create a sustainable development path.

This study does not incorporate provincial-level or sector-specific data, which may have provided more granular insights for policy design. Future work could expand the dataset to include regional or sectoral indicators, thereby obtaining a more comprehensive representation of the underlying dynamics. In addition, applying alternative nonlinear econometric approaches would allow for a more rigorous assessment of the robustness of the findings across different spatial and sectoral contexts.

6. ACKNOWLEDGMENTS

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