Journal of Finance – Marketing Research; Vol. 15, Issue 08; 2024
p-ISSN: 3030-4296; e-ISSN: 3030-430X
DOI: https://doi.org/10.52932/jfm.v15i8

Journal of Finance – Marketing Research
http://jfm.ufm.edu.vn

EFFECTS OF ECONOMIC GROWTH, FOREIGN DIRECT INVESTMENT, ENERGY CONSUMPTION, AND URBANIZATION ON THE ECOLOGICAL FOOTPRINT IN VIETNAM

Bui Thi Thu Thao[1*], Cao Tan Huy[1]
[1]University of Finance – Marketing,Vietnam

ARTICLE INFO

DOI:
10.52932/jfm.v15i8.602

Received:
August 21, 2024
Accepted:
October 24, 2024
Published:
November 25, 2024

Keywords:
Ecological footprint; FDI; GDP; Wavelet.

JEL codes:
C32, O44, Q53

ABSTRACT

This research examines the impacts of economic growth, foreign direct investment, energy consumption, and urbanization on the ecological footprint in Vietnam from 1992 to 2022. The Wavelet Coherence analysis method is employed to evaluate the correlation levels between variables across various periods and frequencies, providing insights into the mechanisms and extent to which these factors influence the environment amidst urbanization and economic development. The research results indicate a robust in-phase relationship among energy consumption, urbanization, and the ecological footprint. Meanwhile, the interaction between economic growth, foreign direct investment, and the ecological footprint is observed to be more intricate and fluctuates over time. Drawing from these insights, the authors recommend adopting targeted sustainable development policies, promoting clean energy usage, and implementing effective urban management strategies to mitigate the adverse environmental impacts of economic growth in Vietnam.

*Corresponding author:
Email: buithao@ufm.edu.vn

1. Introduction

Vietnam is experiencing significant economic development and urbanization while facing serious environmental protection challenges. Understanding the factors influencing environmental quality degradation is crucial and has garnered considerable attention from researchers aiming to devise sustainable development strategies that balance economic growth with environmental protection (Acaroğlu et al., 2023). Many studies use carbon emissions (CO_2) as a proxy variable to assess the degree of environmental degradation, primarily reflecting air pollution from fossil fuel combustion, deforestation, and industrial activities. However, some studies argue that this variable is insufficient for evaluating environmental pollution because it does not address the pollution of other elements like soil and water (Awosusi et al., 2022). Therefore, several researchers use the ecological footprint as a more comprehensive proxy variable for assessing environmental pollution. The term Ecological Footprint was introduced by Canadian scientists over 30 years ago (Rees, 1992; Rees & Wackernagel, 2005). The ecological footprint includes carbon emissions, land and water use, biodiversity, and resource consumption related to an individual, community, company, or country. It represents the land area required to produce the goods and services consumed by an individual or community and absorb the emissions from this consumption. Thus, the ecological footprint should be considered an index measuring human dependency on natural resources by calculating the environment necessary to sustain a specific lifestyle. This index includes components such as grazing land footprint, cropland footprint, fisheries product footprint, forest product footprint, carbon footprint, and built-up land footprint (Aşıcı & Acar, 2016).

Various studies utilizing diverse methodologies have identified different factors, with varying degrees of impact, on environmental quality. In this context, the scholarly landscape related to the ecological effects of economic growth, foreign direct investment (FDI), energy consumption, and urbanization is rich with diverse studies spanning various global regions. These factors have been rigorously examined individually and in combination with other socio-economic variables across different countries, providing a comprehensive understanding of their implications on ecological footprints and broader environmental metrics. In the OECD countries, studies by Baloch et al. (2019) and Destek and Sinha (2020) have explored the complex relationships between economic dynamics and environmental outcomes. These analyses have revealed that economic growth initially leads to increased ecological footprints, demonstrating a U-shaped curve that stabilizes at higher income levels. Research within European countries has similarly highlighted intricate interdependencies. Alola et al. (2019) and Bayar et al. (2020) investigated the effects of energy consumption, alongside other economic factors like GDP and trade openness, and revealed that while renewable energy contributes positively to environmental sustainability, non-renewable energy use and economic expansion often exacerbate environmental degradation. In BRICS and ASEAN countries, research by Danish et al. (2020) and Nathaniel and Khan (2020) has further explored how urbanization and energy consumption directly affect ecological footprints. These studies indicate that while renewable energy and effective resource management can reduce environmental impacts, urbanization, and non-renewable energy use tend to increase them, particularly in rapidly developing regions. Specifically focusing on Vietnam, recent studies by Bui and Phan (2022), Hoang and Ngo (2023), and Tran

(2024) have provided insights into how these factors exacerbate the ecological footprint. These researches highlight the critical need for integrated approaches to understanding and mitigating the environmental impacts of Vietnam's rapid economic and urban development.

The dynamic interplay between economic growth, foreign direct investment, energy consumption, urbanization, and their collective impact on the ecological footprint in Vietnam underscores the practical urgency for detailed research into these relationships. Over the past three decades, Vietnam has maintained robust economic growth rates, peaking at over 9% in the mid-1990s and early 2000s and rebounding strongly post-global financial crises and the COVID-19 pandemic, achieving 8.12% in 2022. This persistent economic expansion, integral to Vietnam's development trajectory, necessitates an investigation into its environmental repercussions. Parallel trends of increasing FDI and energy consumption highlight Vietnam's growing integration into the global economy and its escalating industrial activities, respectively. FDI inflows have shown significant peaks, notably around 2008, suggesting increased industrial activities. Moreover, the near doubling of energy consumption per capita from 1992 to 2022 mirrors the country's heightened energy needs amidst rapid industrialization; Alongside this, the urban population has surged from just over 21% to nearly 39%, intensifying urban environmental stresses such as waste generation and land use changes. Given these developments and the corresponding fourfold increase in the ecological footprint per person, there is a critical need for an integrated analysis that explores how Vietnam's economic growth, FDI, urbanization, and energy consumption are interlinked with environmental sustainability.

In light of the above, while there is a substantial corpus of research on the environmental impacts of critical developmental factors such as economic growth, foreign direct investment, energy consumption, and urbanization, a notable research gap persists in the comprehensive evaluation of these factors within the Vietnamese context. Existing literature predominantly examines these variables either individually or in limited combinations, thereby failing to capture the full spectrum of their collective impacts on the ecological footprint. This deficiency highlights the critical need for an integrated analysis that evaluates how Vietnam's rapid socio-economic developments influence its ecological footprint, a vital measure of environmental sustainability.

This study seeks to address this gap by employing the Wavelet method to investigate the interconnected effects of economic growth, FDI, energy consumption, and urbanization on Vietnam's ecological footprint from 1990-2022. This methodological approach is particularly innovative within the scope of Vietnamese environmental studies. Unlike traditional analytic techniques, the Wavelet method offers a robust framework for analyzing both time and frequency domain data, enabling a comprehensive examination of complex, non-linear interactions among multiple variables over various temporal scales.

The remainder of this paper is structured into four main sections. Section 2 introduces the theoretical framework and empirical research. Section 3 provides a detailed explanation of the research methodology and the data sources utilized. Following this, the findings from the analysis are comprehensively discussed in Section 4. Finally, Section 5 presents several policy recommendations aimed at synthesizing economic development with environmental sustainability, based on the insights garnered from our research findings.

2. Theoretical framework and empirical research

2.1. Theoretical Framework

In the context of globalization and rapid economic development, countries around the world are increasingly facing environmental pressures, with the ecological footprint being one of the key indicators used to assess the impact of human activities on ecosystems. Economic growth, foreign direct investment, energy consumption, and urbanization are core factors influencing a nation's ecological footprint. Each of these factors can have either positive or negative impacts, depending on how countries manage and implement sustainable development policies.

Economic growth and environmental conditions

The Environmental Kuznets Curve (EKC) is a vital model that can be used to explain the relationship between economic growth and environmental quality. According to the EKC, in the early stages of economic development (pre-industrial stage), environmental pollution increases due to industrialization, resource extraction, and increased production (Panayotou, 1997; Dasgupta et al., 2002; Stern, 2004; Sarkodie & Strezov, 2018). However, as the economy reaches a higher income level, environmental protection policies are established, and attention to environmental quality rises, helping a reduction in environmental impact (Grossman & Krueger, 1991). This is explained by the transition from resource-intensive manufacturing industries (industrial stage) to high-tech and service sectors (post-industrial stage) with less environmental impact (Panayotou, 1997; Dasgupta et al., 2002; Stern, 2004; Sarkodie and Strezov, 2018).

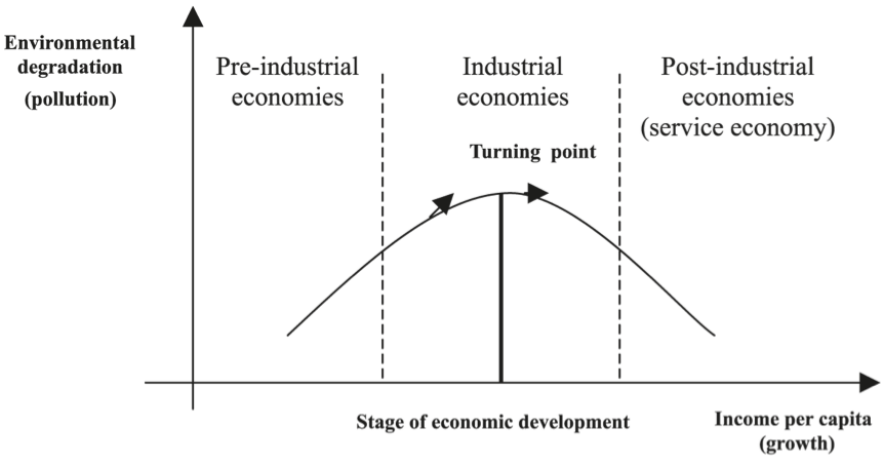

Figure 1. Environmental Kuznets Curve – EKC

Source: Panayotou (1997)

In the context of the ecological footprint, the EKC theory suggests that developed countries can reduce their ecological footprint once they reach a certain level of development and adopt cleaner technologies. Meanwhile, developing countries will likely face increasing ecological footprints due to rapid industrialization and high resource consumption (Dinda, 2004).

Foreign direct investment and environmental conditions

FDI is one of the key drivers of global economic growth, and its impact on the environment has attracted significant research attention. FDI can have both positive and negative effects on the environment, depending on the nature of the industries receiving investment and the

environmental regulations of the host country (Borensztein et al., 1998; Zarsky, 1999). On the one hand, FDI can bring clean technology and environmentally friendly production processes, helping to reduce pollution and improve environmental conditions (Borensztein et al., 1998). This is particularly possible when host countries have high environmental standards and foreign companies adopt advanced technologies. On the other hand, in countries with loose environmental regulations, FDI can lead to increased pollution as foreign companies take advantage of low environmental standards to reduce production costs, resulting in a "race to the bottom" phenomenon (Zarsky, 1999). Regarding the ecological footprint, FDI in energy, manufacturing, and extractive industries can increase the ecological footprint if appropriate environmental control measures are not implemented (Cole, 2006). However, when stringent environmental policies are enforced, FDI can lead to a decrease in the ecological footprint as foreign investors are compelled to adopt cleaner technologies and more sustainable practices (Doytch & Uctum, 2016).

Energy consumption and environmental conditions

Energy consumption is closely linked to environmental quality, particularly when energy is primarily produced from non-renewable sources such as oil, coal, and natural gas. The consumption of fossil fuels not only depletes resources but also causes serious environmental problems, such as greenhouse gas emissions and air pollution (Stern, 2004). Countries that rely on fossil fuels will have larger ecological footprints, while those that transition to renewable energy sources like solar, wind, and hydropower can significantly reduce their ecological footprint (York et al., 2003).

In this regard, the development of renewable energy sources is a key strategy for reducing the environmental impact. However, the implementation of renewable energy technologies requires significant investment in infrastructure and government support policies (Bhattacharyya, 2011). Therefore, the development of sustainable energy technologies depends not only on financial capacity but also on a strong legal framework to promote the energy transition.

Urbanization and environmental conditions

Urbanization is a key factor affecting the environment and the ecological footprint. As urban populations grow, the demand for energy, resources, infrastructure, and public services also increases, putting additional pressure on the environment. Ehrlich and Holdren (1971) developed the IPAT model (Impact = Population × Affluence × Technology) to explain the impact of factors such as population, affluence, and technology on the environment. According to this model, the ecological footprint will increase as population and living standards rise, especially in the context of urbanization. Specifically, rapid urbanization in developing countries can increase the ecological footprint due to higher demand for energy and resources for construction and infrastructure development (Seto et al., 2012). However, technology can help mitigate this impact if green and environmentally friendly technological solutions are applied. Thus, urbanization can present both challenges and opportunities for controlling the ecological footprint, depending on how cities are planned and managed (Grimm et al., 2008).

In light of the above, the theoretical foundations of economic growth, foreign direct investment, energy consumption, and urbanization collectively highlight their significant roles in shaping a nation's ecological footprint. The EKC suggests that economic growth initially leads to increased environmental degradation, but with further development and cleaner technologies, environmental impacts

can be mitigated. FDI, depending on the nature of industries and environmental regulations, can either exacerbate or alleviate ecological pressures through the introduction of cleaner production methods or by exploiting weaker environmental standards. Energy consumption, especially reliance on fossil fuels, is closely tied to a larger ecological footprint, but transitioning to renewable energy sources can reduce this impact. Urbanization, as outlined in the IPAT model, increases the demand for resources and energy, further elevating the ecological footprint unless managed through sustainable urban planning and green technologies. Together, these factors are interrelated, and their combined influence underscores the importance of sustainable economic policies to manage the ecological footprint effectively.

2.2. Empirical research

Factors such as economic growth, foreign direct investment, energy consumption, and urbanization have been the focus of numerous studies on environmental quality in various countries, including Vietnam. These factors have been analyzed either individually or in combination with other socio-economic variables to assess their impact on the ecological footprint and other environmental indicators. These studies have not only examined the direct relationship between economic factors and the environment but have also explored different aspects and methodologies, ranging from measuring the effects of each factor to analyzing them in various national and regional contexts.

Baloch et al. (2019) conducted a study covering the period from 1990 to 2017 in OECD countries, focusing on the relationship between financial development, economic growth, energy innovation, and environmental pollution. The results from the Pooled Mean Group Autoregressive Distributed Lag (PMG/ARDL) model revealed that financial development significantly fosters energy innovation, enhancing environmental quality, and also identified a positive and statistically significant relationship between GDP per capita and GHG emissions. Another research in 24 OECD countries by Destek and Sinha (2020) examined the ecological footprint over the period from 1980 to 2014, focusing on the roles of renewable energy use, non-renewable energy use, and trade openness. The findings from generation panel data methodologies revealed a U-shaped relationship between economic growth and the ecological footprint, indicating that at early stages of economic development, environmental degradation increases, but declines at higher levels of income. Additionally, renewable energy consumption contributes to a reduction in the ecological footprint, while non-renewable energy use exacerbates environmental degradation, further emphasizing the importance of transitioning to cleaner energy sources.

In exploring the environmental impacts of economic activities, numerous studies in European countries have shed light on the complex dynamics between these factors and environmental outcomes. Alola et al. (2019) investigated the relationship between the ecological footprint, GDP, trade openness, fertility rate, and energy consumption (both renewable and non-renewable) across 16 EU countries from 1997 to 2014. Utilizing the PMG-ARDL model, the results showed that non-renewable energy consumption depletes environmental quality, contributing to greater environmental degradation. In contrast, renewable energy use was found to improve environmental sustainability, reinforcing the critical role of clean energy in reducing the ecological footprint. Similarly, Bayar et al. (2020) explored the impact of financial development, primary energy consumption, and economic growth on CO_2 emissions in 11 post-transition European economies from 1995 to 2017. Through panel cointegration

and causality analyses, they identified a two-way causality between primary energy consumption, economic growth, and CO2 emissions, suggesting that these factors are closely interlinked. The study also found that primary energy consumption positively affects CO_2 emissions, indicating that increased energy use and financial expansion contribute to environmental pressures in these economies. In the case of Turkey, Acaroğlu et al. (2023) analyzed data from 1971 to 2015, looking at the relationship between economic growth, trade openness, primary energy consumption, coal consumption, and hydroelectricity consumption on CO_2 emissions and the ecological footprint. The findings from the Autoregressive Distributed Lag (ARDL) model showed that coal consumption raised both CO_2 emissions and the ecological footprint, whereas hydroelectric energy reduced CO_2 emissions but had no significant impact on the ecological footprint.

In the BRICS economies, Danish et al. (2020) examined the effects of real income, renewable energy, urbanization, and natural resource rent on the ecological footprint from 1992 to 2016. Using FMOLS and DOLS models, their study found that renewable energy, urbanization, and natural resource rent all contributed to a decrease in the ecological footprint, thereby enhancing environmental quality. This highlights the potential positive role of urbanization and natural resource management when supported by renewable energy usage in reducing environmental impacts. Ullah et al. (2021) explored data from 1996 to 2018 across 15 economies to investigate the relationship between renewable energy consumption, natural resource rent, and the ecological footprint. Using the Panel Smooth Transition Model, the study revealed a negative relationship between renewable energy consumption and the ecological footprint, implying that renewable energy helps reduce environmental pressures. However, natural resource rent was found to have a positive relationship with the ecological footprint, indicating that resource extraction increases environmental degradation.

The relationship between development variables and environmental impact appears similarly intricate but with unique regional characteristics. Nathaniel and Khan (2020) analyzed the relationship between renewable and non-renewable energy consumption, economic growth, urbanization, and the ecological footprint in ASEAN countries from 1990 to 2016, using the STIRPAT model. Their findings indicated that economic growth, trade, and non-renewable energy consumption significantly contribute to environmental degradation. Additionally, the study revealed a one-way causality from urbanization to non-renewable energy consumption, suggesting that as urban areas expand, there is increased reliance on non-renewable energy sources, further worsening environmental conditions. Bui et al. (2020) examined the effects of economic growth, electricity consumption, and urbanization on the ecological footprint in ASEAN countries over the period from 1981 to 2016. By applying the Mean Group (MG), PMG, and Dynamic Fixed Effects (DFE) models, they found that both economic growth and urbanization positively impact the ecological footprint in the short and long term, implying that these factors exacerbate environmental pressures. However, electricity consumption had no significant impact on the ecological footprint in the short term but contributed negatively to it in the long term. More recently, Le (2024) focused on the relationship between economic growth, renewable energy, CO_2 emissions, and the material footprint in Southeast Asia from 2000 to 2021. Results from the PVAR model with GMM regression concluded that economic growth harms the environment, a common trade-off seen in emerging markets within the region. This research underscores

the environmental challenges faced by these economies as they pursue rapid growth while balancing sustainability efforts.

Focusing on Vietnam, research efforts continue to analyze the nuanced dynamics between development and environmental sustainability. Notably, Bui and Phan (2022) investigated the interconnections between FDI, economic growth, and energy consumption with the ecological footprint from 1986 to 2019, using the Quantile-on-Quantile (QQ) approach to underline how these factors exacerbate environmental degradation within the country. Their results showed that FDI, economic growth, and energy consumption all have a positive impact on the ecological footprint, suggesting that these factors contribute to environmental degradation. Hoang and Ngo (2023) examined the effects of Information and Communication Technology, GDP, and renewable energy on CO_2 emissions in Vietnam from 2000 to 2020, also using the QQ method. Their findings revealed that GDP increases CO_2 emissions across different quantiles, while renewable energy helps reduce emissions. The study by Tran (2024) on 31 emerging economies, including Vietnam, from 1995 to 2017, focused on financial development, GDP, FDI, urbanization, and their effects on the ecological footprint. Using a Panel Threshold Regression (PTR) model, the research found a positive relationship between economic growth, FDI, urbanization, and environmental degradation, with diminishing effects after a certain threshold. This suggests that while these factors contribute to environmental harm, their impact decreases beyond a certain level of development.

Regarding methodologies, empirical studies on the impact of the aforementioned factors on environmental quality have employed a diverse array of analytical methods, including Mean Group (MG), Pooled Mean Group (PMG), Dynamic Fixed Effects (DFE), Fully Modified Ordinary Least Squares (FMOLS), Dynamic Ordinary Least Squares (DOLS), Quantile-on-Quantile (QQ) regression, Autoregressive Distributed Lag (ARDL), and Panel Threshold Regression (PTR), among others. One common challenge across these methods is the assumption of linearity or homogeneity, which can oversimplify the intricate relationships between economic growth, FDI, energy consumption, urbanization, and ecological footprint. Furthermore, these traditional methods often encounter difficulties in analyzing dynamic and non-linear relationships, especially in contexts where environmental impacts evolve due to varying factors like policy changes or technological advancements. This limitation creates a potential gap in capturing the full complexity of environmental dynamics in a rapidly changing global context.

Despite the growing body of literature on the environmental impacts of economic growth, foreign direct investment, energy consumption, and urbanization, considerable research gaps remain, particularly in the context of Vietnam. While numerous studies have explored individual or partial relationships between these factors and environmental quality, research specifically integrating all these elements—economic growth, FDI, energy consumption, and urbanization—within a single framework is sparse in Vietnam. Combining all these factors is essential because they collectively represent the broader socio-economic development trajectory of a country, which is intrinsically linked to environmental quality. Economic growth and FDI can lead to increased energy consumption and accelerated urbanization, which in turn may result in significant environmental degradation if not managed properly. Examining these factors together can more effectively identify how Vietnam's rapid economic expansion and urbanization are impacting its ecological footprint, thereby aiding in the development of integrated policy

solutions that ensure sustainable growth while mitigating negative environmental impacts. This comprehensive analysis is pivotal for understanding the full scope of interactions and trade-offs between economic development and environmental sustainability in Vietnam.

Moreover, from a methodological perspective, employing the Wavelet approach to investigate the combined effects of economic growth, FDI, energy consumption, and urbanization on the ecological footprint will offer a different perspective from previous studies in Vietnam. The wavelet method distinguishes itself by transcending traditional analytical limitations, offering a comprehensive framework that integrates both time and frequency domain analyses. This method is not bound by the stringent assumptions of classical regression techniques, enabling a more expansive evaluation of data characteristics. Specifically, it facilitates an intricate examination of the temporal dynamics and frequency-specific behaviors of variables, capturing both transient and enduring phenomena as well as the complex, non-linear interactions among them. Such capabilities are particularly advantageous in contexts like Vietnam, where rapid socioeconomic transformations necessitate precise measurement of their environmental impacts. The flexibility and breadth of the wavelet approach render it exceptionally suitable for dissecting the multifaceted effects of economic and urban development on ecological footprints, thereby providing a robust tool for environmental impact assessment in dynamically changing settings.

3. Research methodology and data

3.1. Research methodology

This study utilizes the Wavelet methods to comprehensively analyze the dynamic relationships between economic growth, foreign direct investment, energy consumption, urbanization, and the ecological footprint in Vietnam from 1992 to 2022. The variables studied include:

Ecological footprint (EF) serves as the key indicator of environmental quality, drawing on the foundational work of Rees (1992), Rees and Wackernagel (2005), and more recent studies such as those by Alola et al. (2019), Bayar et al. (2020), Baloch et al. (2021), Acaroğlu et al. (2023), and Tran (2024). This variable will be analyzed with each of the economic and developmental factors under investigation.

Economic growth is quantified through the annual growth rate of Gross Domestic Product (GDP), expressed as a percentage, which reflects the overall economic performance of Vietnam during the study period.

Foreign direct investment (FDI) is assessed by the ratio of FDI inflows to GDP, capturing the extent of foreign capital integration into the Vietnamese economy.

Energy consumption (EC) is measured by per capita energy use, expressed in kilowatt-hours (kWh), offering insights into the energy demands of the population and its potential environmental impacts.

Urbanization (Urb) is represented by the percentage of the population residing in urban areas, which serves as an indicator of the extent of urban development and its associated environmental consequences.

These approaches have been grounded in the work of prominent scholars such as Beckerman (1992), Solarin and Al-Mulali (2018), Ashraf et al. (2021), Bayar et al. (2020), Nathaniel and Khan (2020), Baloch et al. (2021), Lin et al. (2021), and Acaroğlu et al. (2023), whose studies have informed the selection of variables and the interpretation of results.

Regarding the research methodology, the Wavelet Coherence method allows for

measuring the correlation between two-time series of variable pairs over time and frequency, emphasizing periods when data series occur simultaneously (Torrence & Compo, 1998). Meanwhile, the cross-wavelet transform is used to explore lead-lag relationships between variables, providing insights into cause-and-effect interactions within the economic-environmental interface (Maraun & Kurths, 2004). Compared to traditional time series analysis methods, the Wavelet approach offers several advantages, such as addressing issues related to data sparsity in short periods, and simultaneously considering the presence of short-term and long-term decisions at different frequencies (Le, 2022). In this study, the cross-wavelet transform method analyzes the correlation between two-time series x(t) and y(t) over the same time-frequency space. This cross-wavelet transform is described as follows:

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

With u representing the position, s denoting the scale corresponding to each frequency domain, and * indicating the complex conjugate relationship between the two series. This setup forms the basis for examining the interactions and relative phases between variables at specific times and scales within the time-frequency space. This approach enables the identification of when and how the two variables interact, potentially revealing causal relationships within their dynamic interactions.

3.2. Research data

This study is conducted using data from Vietnam for the period 1992 – 2022. The data are compiled annually from the World Bank's World Development Indicators (WDI, 2024), Our World in Data (OWID, 2024), and the Global Footprint Network (GFN, 2024). The sources of data and research variables are presented in Table 1 below.

Table 1. Description of Research Variables and Data Sources

Symbol	Variable Name	Description and Measurement Unit	Data Source
EF	Ecological Footprint	The measure of the demand on Earth's ecosystems, representing the amount of biologically productive land and water area required to produce the resources an individual consumes and to absorb their waste, expressed in global hectares per person. (ConsPerCap)	GFN (2024)
GDP	Economic Growth	Annual growth rate of Gross Domestic Product at constant 2015 prices (%)	WDI (2024)
FDI	Foreign Direct Investment	The ratio of Foreign Direct Investment inflows to Gross Domestic Product expressed as a percentage (%)	WDI (2024)
EC	Energy Consumption	Average energy consumed per person, measured in kilowatt-hours (kWh)	OWID (2024)
Urb	Urbanization	The proportion of the total population living in urban areas, expressed as a percentage of the total population (%)	WDI (2024)

4. Results and discussion

4.1. Descriptive statistics of variables

The descriptive statistics for the variables Economic Growth (GDP), Foreign Direct Investment (FDI), Energy Consumption (EC), Urbanization (Urb), and Ecological Footprint (EF) in Vietnam during the period 1992-2022 (*see Appendix 1 online*). The GDP variable has an average value of 6.738, with its values ranging from a minimum of 2.554 to a maximum of 9.540, and it shows a standard deviation of 1.580, indicating moderate variability. The FDI variable exhibits a higher degree of variability, with a mean of 5.588 and a standard deviation of 2.190. Its values range from a minimum of 3.390 to a maximum of 11.939. Notably, the FDI variable does not follow a normal distribution, as indicated by the Jarque-Bera test result, which is significant at the 1% level (Jarque-Bera = 9.974, p = 0.007).

The EC variable, representing energy consumption, has a mean of 5828.712, with a wide range from 1229.321 to 12670.410, and a standard deviation of 3793.288, reflecting substantial variability in energy consumption across observations. The Urb variable, which measures urbanization, has a mean value of 28.975, with a standard deviation of 5.510. Its values range from 21.006 to 38.766, indicating variability in the level of urbanization. The EF variable, representing the ecological footprint, has a mean value of 1.392 and a standard deviation of 0.591, with its values ranging from a minimum of 0.602 to a maximum of 2.432.

The Jarque-Bera test results suggest that most of the variables, including GDP, EC, Urb, and EF, approximate normal distribution, except FDI, which deviates significantly from normality. The probability values associated with the Jarque-Bera test further confirm that GDP (p = 0.162), EC (p = 0.222), Urb (p = 0.341), and EF (p = 0.308) are not significantly different from normal distribution, indicating that these variables are relatively normally distributed within the sample. This statistical summary provides key insights into the characteristics and distributional properties of the variables under study.

4.2. Correlation matrix

The correlation matrix (*see Appendix 2 online*) provides an insightful analysis of the relationships between EF and the variables GDP, FDI, EC, and Urb. The correlation coefficients reveal several key patterns. Firstly, GDP shows a negative correlation with EF (-0.461), suggesting that as economic growth increases, the ecological footprint tends to decrease, albeit at a moderate level. Similarly, FDI also exhibits a negative correlation with EF (-0.379), but the effect is weaker compared to GDP. On the other hand, the relationship between EC and EF is strikingly different. The correlation is strongly positive (0.988), indicating that increases in energy consumption are almost directly mirrored by increases in the ecological footprint. Urbanization (Urb) shows an even higher positive correlation with EF (0.997), indicating that changes in urbanization levels are almost perfectly aligned with changes in the ecological footprint.

These correlations collectively highlight the complex interplay between economic development, foreign direct investment, energy use, and urbanization in shaping environmental outcomes. While economic growth and foreign investment seem to have a mitigating effect on the ecological footprint, energy consumption and urbanization emerge as dominant factors that exacerbate environmental degradation. The near-perfect correlations for EC and Urb with EF suggest that efforts to reduce the ecological footprint may need to focus heavily on managing energy consumption and urbanization processes to achieve significant environmental benefits.

4.3. Wavelet coherence

The results of the cross-wavelet analysis are displayed in Appendix 3, 4, 5, and 6 (*see Appendix 3,4,5 and 6 online*), illustrating the varying correlation between EF and the variables GDP, FDI, EC, and Urb over time and across frequencies, with distinct differences observed in short-term and long-term periods. The study period is represented on the horizontal axis (from 1992 to 2022), and frequency is depicted on the vertical axis (scaled from 1 to 8). Regions with darker colors indicate periods and frequencies where the relationships between the variables are strongest.

Relationship between EF and GDP: The correlation between GDP and EF was not clear before 2010. Subsequently, the correlation level gradually increased and became more distinct but remained weak. From 2018 onwards, the relationship between GDP and EF became significantly stronger, with a high degree of correlation. During this period, the arrows on the graph primarily point to the right, with some pointing upward and others downward, indicating that the two variables are in phase and out of phase at different times. This suggests that economic development impacts the ecological footprint non-uniformly. These findings are consistent with previous research by Alola et al. (2019), Baloch et al. (2019), Destek and Sinha (2020), Nathaniel and Khan (2020), Bui et al. (2020), and Bui and Phan (2022). In the context of Vietnam, strong economic growth since 2010 has led to the expansion of heavy industries and increased exploitation of resources, which directly impacts the ecological footprint. Although the relationship between GDP and ecological footprint fluctuates unevenly, the general trend indicates that periods of rapid economic growth are often associated with significant increases in energy use and non-renewable resources, thereby exerting increased pressure on the environment.

Relationship between EF and FDI: The correlation between FDI and EF has remained low to moderate throughout most of the study period. The relationship between FDI and EF was only distinct and notable for a brief period from about 2004 to 2007, yet there is no definitive evidence of whether the relationship was positive or negative. These results suggest that the relationship between foreign direct investment and the ecological footprint is unstable, varying over time and frequency, underscoring the need to consider other economic context factors to better understand how and to what extent FDI impacts the environment (Bui and Phan, 2022). In Vietnam, where the pursuit of FDI is a key component of economic strategy, these findings take on added importance. The results showing a low to moderate, and occasionally distinct, correlation between FDI and the ecological footprint during specific periods illustrate the complex nature of environmental impacts linked to foreign investments. This inconsistency underlines the need for a nuanced understanding of how FDI influences environmental outcomes, suggesting that the environmental impacts of foreign investments in Vietnam are influenced by varying factors, including the industrial sectors involved and the technologies they employ.

Relationship between EF and EC: In the period before 2000, the correlation between EC and EF was negligible, ranging from low to moderate. However, starting in 2004, a high correlation region in yellow to red appeared at low frequencies, indicating a close relationship between energy consumption levels and the ecological footprint. The in-phase relationship between EC and EF is depicted by arrows mostly pointing to the right, meaning that as energy consumption increases, so does the ecological footprint, and vice versa. This result aligns with previous studies on the negative impact of energy consumption on environmental quality

(Bayar et al., 2020; Nathaniel and Khan, 2020; Baloch et al., 2021; Acaroğlu et al., 2023; Bui et al., 2020; Bui & Phan, 2022; Hoang & Ngo, 2023). These findings are particularly relevant given the country's rapid industrialization and urbanization during this period. This close relationship indicates that Vietnam's developmental strategies, heavily reliant on energy-intensive industries, directly impact its environmental sustainability. As the economy continues to grow and the energy demand escalates, the ecological consequences become increasingly apparent, underscoring the critical need for Vietnam to monitor and manage its energy consumption patterns more effectively to mitigate adverse environmental impacts.

Relationship between EF and Urb: Initially, Urb had a short-term impact on EF. However, from 2004 onwards, the graph indicates a strong and stable relationship between the level of urbanization and the ecological footprint. The arrows in this high-correlation area mostly point to the right, indicating an in-phase relationship between the Urb and EF variables. This means that increases in urbanization typically coincide with increases in the ecological footprint, and vice versa. This finding is consistent with research by Bui et al. (2020), Lin et al. (2021), and Acaroğlu et al. (2023). The observed strong and stable relationship between urbanization and the ecological footprint from 2004 reflects the rapid expansion of urban areas and the associated environmental pressures. As cities in Vietnam continue to grow, the demand for infrastructure, housing, and services increases, leading to higher consumption of resources and greater waste generation, both of which significantly contribute to the ecological footprint. This trend highlights the significant challenge of managing the environmental impacts that accompany the rapid urbanization in Vietnam, particularly as the urban population continues to expand.

5. Conclusion and policy implications

5.1. Conclusion

Based on the comprehensive analysis conducted using wavelet methods, this study provides crucial insights into the complex and dynamic relationships between key economic and developmental variables—economic growth (GDP), foreign direct investment (FDI), energy consumption (EC), and urbanization (Urb)—and environmental degradation, as measured by the Ecological Footprint (EF) in Vietnam from 1992 to 2022. The research results underscore the varying degrees of correlation between these variables over different periods and frequencies, highlighting both short-term and long-term distinctions. Notably, energy consumption and urbanization exhibit consistently significant and synchronous correlations with the ecological footprint, emphasizing the significant environmental pressures associated with these factors in Vietnam. These results suggest that the rapid rate of urbanization and the reliance on high levels of energy consumption, particularly from non-renewable sources, have been key contributors to the country's growing ecological footprint.

In contrast, the correlations between economic growth, foreign direct investment, and the ecological footprint are more complex and less stable, fluctuating over time and across different frequencies. While economic growth has shown a stronger relationship with the ecological footprint in recent years, the impact of foreign direct investment remains inconsistent, reflecting the varying nature of FDI's influence on environmental quality depending on the types of investments and the regulatory environment. These findings highlight the need to adopt more targeted policies that address the environmental impacts of economic activities, particularly in sectors that contribute significantly to the ecological footprint in Vietnam.

5.2. Policy implications

Based on the findings of the study, the authors propose several policy implications aimed at minimizing the impact of the identified factors on the ecological footprint and environmental quality in Vietnam:

Firstly, regarding economic growth, policies encouraging the adoption of green economic practices should be intensified to mitigate the impacts of identified factors on the environment in Vietnam. The strengthening of investment in clean technologies and the enhancement of energy efficiency in key industries are seen as essential to minimizing the ecological footprint. Additionally, the promotion of environmentally friendly business models (such as renewable energy companies, sustainable agriculture practices, and green technology firms) and the enhancement of sustainable natural resource management are advocated by policies. Through these measures, economic growth can be achieved in Vietnam while still protecting environmental quality, aiming for long-term sustainable development.

Secondly, concerning foreign direct investment, Vietnam needs to consider implementing policy measures to control and guide capital flows into environmentally friendly projects. Initially, a clear evaluation system should be established to determine the environmental impact of FDI projects, subsequently enforcing mandatory environmental standards for foreign investors. Moreover, the inconsistency in the relationship between FDI and the ecological footprint highlights the complex and variable nature of how foreign investments affect environmental outcomes in Vietnam, influenced by factors such as the industries and technologies involved, necessitating tailored regulatory strategies for each industry to ensure that FDI not only drives economic growth but also complies with the highest environmental standards, especially in highly pollutive sectors. Additionally, Vietnam could facilitate the transfer of green technologies from developed countries to improve energy efficiency and minimize negative environmental impacts. This not only aids Vietnam in achieving sustainable development goals but also enhances the living environment for its citizens.

Thirdly, regarding energy consumption, Vietnam should implement strategic measures to address the strong correlation between energy use and ecological footprint as highlighted by the research. It is imperative to promote energy efficiency across various sectors and encourage the adoption of renewable energy sources (such as solar, wind, and biomass energy). Policy initiatives could include incentives for businesses to reduce energy consumption and invest in cleaner technologies. Moreover, public awareness campaigns to educate citizens on the benefits of energy conservation and sustainable practices can further aid in reducing the national ecological footprint. These measures are essential to align Vietnam's energy consumption with global environmental standards and reduce its ecological impact.

Lastly, in relation to urbanization, Vietnam needs to adopt strategies that mitigate the environmental impact associated with the expansion of urban areas. Urban planning should integrate green spaces and sustainable architecture to reduce the ecological footprint. Additionally, policies should focus on improving public transportation systems to decrease reliance on private vehicles, thus reducing emissions and energy consumption. Implementing waste reduction and recycling initiatives in urban settings is also crucial to managing resource consumption and waste output effectively. Through these measures, Vietnam can better manage the environmental consequences of its rapid urbanization while ensuring sustainable urban growth.

5.3. Limitations and future research directions

This research focuses exclusively on data from Vietnam, so the findings may not be fully applicable to other regions or countries. The use of wavelet correlation analysis by the authors for time series data could also be affected by the specific wavelet functions and parameters chosen. To enhance the accuracy of future research, it would be beneficial to explore different types of wavelets and optimize the parameters used in the analysis. Additionally, expanding the study to include data from other countries and regions could provide a more comprehensive understanding of the observed relationships.

References

Acaroğlu, H., Kartal, H. M., & García Márquez, F. P. (2023). Testing the environmental Kuznets curve hypothesis in terms of ecological footprint and CO2 emissions through energy diversification for Turkey. *Environmental Science and Pollution Research*, *30*, 63289-63304. https://doi.org/10.1007/s11356-023-26278-w

Alola, A. A., Bekun, F. V., & Sarkodie, S. A. (2019). Dynamic impact of trade policy, economic growth, fertility rate, renewable and non-renewable energy consumption on ecological footprint in Europe. *Science of the Total Environment*, *685*, 702-709. https://doi.org/10.1016/j.scitotenv.2019.05.139

Ashraf, A., Doytch, N., & Uctum, M. (2021). Foreign direct investment and the environment: Disentangling the impact of greenfield investment and merger and acquisition sales. *Sustainability Accounting, Management and Policy Journal*, *12*(1), 51-73. https://doi.org/10.1108/SAMPJ-04-2019-0184

Aşıcı, A. A., & Acar, S. (2016). Does income growth relocate ecological footprint? *Ecological Indicators, 61*, 707-714. https://doi.org/10.1016/j.ecolind.2015.10.022

Awosusi, A. A., Adebayo, T. S., Kirikkaleli, D., & Altuntaş, M. (2022). Role of technological innovation and globalization in BRICS economies: policy towards environmental sustainability. *International Journal of Sustainable Development & World Ecology*, *29*(7), 593-610.

Baloch, M. A., Zhang, J., Iqbal, K., & Iqbal, Z. (2019). The effect of financial development on ecological footprint in BRI countries: Evidence from panel data estimation. *Environmental Science and Pollution Research International*, *26*(6), 6199-6208. https://doi.org/10.1007/s11356-018-3992-9

Baloch, Z. A., Tan, Q., Kamran, H. W., Nawaz, M. A., Albashar, G., & Hameed, J. (2022). A multi-perspective assessment approach of renewable energy production: policy perspective analysis. *Environment, Development and Sustainability*, *24*, 2164-2192. https://doi.org/10.1007/s10668-021-01524-8

Bayar, Y., Diaconu, L., & Maxim, A. (2020). Financial development and CO2 emissions in post-transition European Union countries. *Sustainability*, *12*(7). https://doi.org/10.3390/su12072640

Beckerman, W. (1992). Economic growth and the environment: Whose growth? Whose environment? *World Development*, *20*(4), 481-496. https://doi.org/10.1016/0305-750X(92)90038-W

Bhattacharyya, S. C. (2011). *Energy economics: Concepts, issues, markets and governance*. London: Springer.

Borensztein, E., De Gregorio, J., & Lee, J. W. (1998). How does foreign direct investment affect economic growth? *Journal of International Economics, 45*(1), 115-135. https://doi.org/10.1016/S0022-1996(97)00033-0

Bui, H. N., Canh, C. H., Bui, T. K., Nguyen, H. K., Nguyen, T. L. (2020). Tăng trưởng kinh tế, tiêu thụ điện, tỉ lệ đô thị hóa và dấu chân sinh thái: Thực nghiệm ở các nước ASEAN [The impact of economic growth, electricity consumption and urbanization on ecological footprint: Evidence from ASEAN countries]. *Tạp chí nghiên cứu Kinh tế và Kinh doanh Châu Á*, *31*(8), 05-24. https://digital.lib.ueh.edu.vn/handle/UEH/62369

Bui, H. N., Phan, T. L. (2022). Linking foreign direct investment, economic growth, energy consumption and ecological footprint in Vietnam: Evidence from quantile on quantile approach. *Science & Technology Development Journal: Economics-Law & Management*, *6*(4), 3855-3866. https://doi.org/10.32508/stdjelm.v6i4.995

Cole, M. A. (2006). Does foreign direct investment increase the environmental Kuznets curve? *Environment and Development Economics, 9*(4), 427-448. https://doi.org/10.1017/S1355770X04001592

Danish, Ulucak, R., & Khan, S. U. D. (2020). Determinants of the ecological footprint: role of renewable energy, natural resources, and urbanization. *Sustainable Cities and Society*, *54*. https://doi.org/10.1016/j.scs.2019.101996

Dasgupta, S., Laplante, B., Wang, H., & Wheeler, D. (2002). Confronting the environmental Kuznets curve. *Journal of economic perspectives*, *16*(1), 147-168. https://doi.org/10.1257/0895330027157

Destek, M. A., & Sinha, A. (2020). Renewable, non-renewable energy consumption, economic growth, trade openness, and ecological footprint: Evidence from Organisation for Economic Co-operation and Development countries. *Journal of Cleaner Production*, *242*. https://doi.org/10.1016/j.jclepro.2019.118537

Dinda, S. (2004). Environmental Kuznets Curve hypothesis: A survey. *Ecological Economics, 49*(4), 431-455. https://doi.org/10.1016/j.ecolecon.2004.02.011

Doytch, N., & Uctum, M. (2016). Globalization and the environmental impact of sectoral FDI. *Economic Systems*, *40*(4), 582-594.

Ehrlich, P. R., & Holdren, J. P. (1971). Impact of population growth. *Science, 171*, 1212-1217. https://doi.org/10.1126/science.171.3977.1212

Global Footprint Network (2024). *Global Footprint Network Report 2024*. https://www.footprintnetwork.org

Grimm, N. B., Faeth, S. H., Golubiewski, N. E., Redman, C. L., Wu, J., Bai, X., & Briggs, J. M. (2008). Global change and the ecology of cities. *Science, 319*(5864), 756-760. https://doi.org/10.1126/science.1150195

Grossman, G. M., & Krueger, A. B. (1991). Environmental impacts of a North American free trade agreement. In *National Bureau of Economic Research Working Paper*. https://doi.org/10.3386/w3914

Hoang, T. X., & Ngo, T. H. (2023). Phân tích tác động của ICT, GDP và REN đến khí thải CO2 tại Việt Nam [The Effects of ICT, GDP, and Renewable Energy on CO2 Emissions in Vietnam]. *Tạp chí Kinh tế và Kinh doanh*, *3*(3). https://doi.org/10.57110/jebvn.v3i3.186

Le, T. H. (2022). Connectedness between nonrenewable and renewable energy consumption, economic growth and CO2 emission in Vietnam: New evidence from a wavelet analysis. *Renewable Energy*, *195*, 442-454. https://doi.org/10.1016/j.renene.2022.05.083

Le, T. T. H. (2024). Năng lượng tái tạo, dấu chân vật chất, tăng trưởng kinh tế và ô nhiễm môi trường tại các thị trường mới nổi Đông Nam Á [Renewable Energy, Material Footprint, Economic Growth, and Environmental Pollution in Southeast Asia's Emerging Market]. *Tạp Chí Kinh Tế Và Phát triển*, *321*(2), 40-49. https://js.ktpt.edu.vn/index.php/jed/article/view/1677

Lin, X., Zhao, Y., Ahmad, M., Ahmed, Z., Rjoub, H., & Adebayo, T. S. (2021). Linking innovative human capital, economic growth, and CO2 emissions: an empirical study based on Chinese provincial panel data. *International Journal of Environmental Research and Public Health*, *18*(16). https://doi.org/10.3390/ijerph18168503

Maraun, D., & Kurths, J. (2004). Cross wavelet analysis: significance testing and pitfalls. *Nonlinear Processes in Geophysics*, *11*(4), 505-514. https://doi.org/10.5194/npg-11-505-2004

Nathaniel, S., & Khan, S. A. R. (2020). The nexus between urbanization, renewable energy, trade, and ecological footprint in ASEAN countries. *Journal of Cleaner Production*, *272*. https://doi.org/10.1016/j.jclepro.2020.122709

Our World in Data (2024). *Global Data Report 2024*. Retrieved from https://ourworldindata.org

Panayotou, T. (1997). Demystifying the environmental Kuznets curve: turning a black box into a policy tool. *Environment and Development Economics*, *2*(4), 465-484. https://doi.org/10.1017/S1355770X97000259

Rees, W. (1992). Ecological footprints and appropriated carrying capacity: What urban economics leaves out. *Environment and Urbanization, 4*(2), 121-130. https://doi.org/10.1177/095624789200400212

Rees, W. E., & Wackernagel, M. (2005). Ecological footprints and appropriated carrying capacity: Measuring the natural capital requirements of the human economy. In M. Redclift (Ed.). *Sustainability: Sustainability Indicators, 4*, 151-181. Taylor & Francis.

Sarkodie, S. A., & Strezov, V. (2018). Empirical study of the environmental Kuznets curve and environmental sustainability curve hypothesis for Australia, China, Ghana and USA. *Journal of Cleaner Production*, *201*, 98-110. https://doi.org/10.1016/j.jclepro.2018.08.039

Seto, K. C., Güneralp, B., & Hutyra, L. R. (2012). Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *Proceedings of the National Academy of Sciences, 109*(40), 16083-16088. https://doi.org/10.1073/pnas.1211658109

Solarin, S. A., & Al-Mulali, U. (2018). Influence of foreign direct investment on indicators of environmental degradation. *Environmental Science and Pollution Research International*, *25*, 24845-24859. https://doi.org/10.1007/s11356-018-2562-5

Stern, D. I. (2004). The rise and fall of the Environmental Kuznets Curve. *World Development, 32*(8), 1419-1439. https://doi.org/10.1016/j.worlddev.2004.03.004

Torrence, C., & Compo, G. P. (1998). A practical guide to wavelet analysis. *Bulletin of the American Meteorological Society*, *79*(1), 61-78. https://doi.org/10.1175/1520-0477(1998)079%3C0061:APGTWA%3E2.0.CO;2

Tran, T. T. P (2024). Tác động của phát triển tài chính đến dấu chân sinh thái: Bằng chứng thực nghiệm tại các quốc gia đang phát triển và mới nổi [The effect of financial development on ecological footprint: Empirical evidence from developing and emerging countries]. *Tạp chí Kinh tế và Phát triển*, *321*(2), 50-59.

Ullah, A., Zhang, Q., Raza, S. A., & Ali, S. (2021). Renewable energy: is it a global challenge or opportunity? Focusing on different income level countries through Panel Smooth Transition Regression Model. *Renewable Energy*, *177*, 689-699.

World Bank (2024). *World Development Indicators 2024*. Washington, DC: The World Bank. https://databank.worldbank.org/source/world-development-indicators

York, R., Rosa, E. A., & Dietz, T. (2003). Footprints on the earth: The environmental consequences of modernity. *American Sociological Review, 68*(2), 279-300. https://doi.org/10.2307/1519769

Zarsky, L. (1999). Havens, halos and spaghetti: Untangling the evidence about foreign direct investment and the environment. In *Foreign direct investment and the environment OECD processing,* 47-74. OECD Publishing. https://www.oecd-ilibrary.org/docserver/9789264266315-en.pdf?expires=1730167858&id=id&accname=-guest&checksum=284E69B1DE150907D1CC0F8F615ED581#page=49