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The Impact of Greenhouse Gas Emissions on GDP per Capita: A Multi-Scale Analysis Using the Wavelet Approach

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ABSTRACT

This study investigates the dynamic relationship between greenhouse gas (GHG) emissions and GDP per capita in Côte d'Ivoire over the period 1991-2023. Using the continuous wavelet transform (CWT), we explore the time-frequency interactions between carbon dioxide (CO_2) emissions and economic growth. Unlike conventional econometric models, the wavelet approach allows for the decomposition of signals into multiple time scales, thereby capturing both short-term fluctuations and long-term structural patterns. The results reveal that GDP per capita exhibits strong spectral activity at medium-term scales, corresponding to significant macroeconomic shifts. CO_2 emissions also demonstrate medium- and long-term cyclical patterns, suggesting structural transformations in energy consumption and production. Wavelet coherence analysis confirms a robust, scale-dependent correlation between GDP and CO_2, particularly at intermediate scales, highlighting a persistent coupling between economic growth and environmental impact. These findings underscore the importance of adopting multiscale tools to inform climate and economic policy in developing countries.

Keywords: Greenhouse Gas Emissions, GDP Per Capita, Wavelet Analysis, Côte d'Ivoire, Environmental Economics, Economic Growth, CO_2

JEL Classifications: Q56, Q54, O44, C63, C32

1. INTRODUCTION

In recent decades, the issue of sustainable economic development has emerged as a major concern for both industrialized and developing countries. Economic growth, often measured by per capita income, is frequently accompanied by an increase in greenhouse gas (GHG) emissions, particularly carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). These emissions are the primary drivers of climate change, whose economic impacts can be profound and vary significantly across regions and time periods. For developing countries—especially those in West Africa such as Côte d'Ivoire—the pursuit of sustainable economic growth faces the challenge of reducing greenhouse gas emissions without undermining poverty reduction goals. Côte d'Ivoire, whose economy relies heavily on agriculture, natural resources, and services, maintains a relatively moderate emissions profile at the global level, yet emissions have been steadily increasing. At the same time, the country has experienced a gradual rise in per capita income, albeit with marked fluctuations linked to economic and political cycles.

Several studies have examined the relationship between economic growth and GHG emissions, but the results remain inconclusive. Some highlight short-term positive effects (e.g., through industrialization), while others emphasize long-term negative consequences such as natural resource degradation, climate-related disasters, and agricultural losses.

In this context, this article aims to investigate the dynamic relationship between GHG emissions and per capita income in Côte d'Ivoire using a multi-scale methodological approach. Unlike traditional econometric models, we employ the Continuous Wavelet Transform (CWT), which allows for the exploration of the joint variability of time series across different time scales. This method has the advantage of capturing non-stationary structures and detecting local regularities often hidden in global linear models. By combining this approach with spectral coherence analysis between income (REV) and CO_2 emissions, our study seeks to highlight the periods and frequency ranges where economic growth is closely linked to emission dynamics, thereby providing useful insights for economic and environmental policy-making.

The remainder of the article is structured as follows. The first section outlines our analytical framework, namely the asset évaluation model and the wavelet décomposition méthode. We then describe the data and discuss the results of our décomposition. The third section presents the findings of both in-sample and out-of-sample predictive regressions.

2. THEORETICAL AND EMPIRICAL BACKGROUND

This study aims to empirically examine the impact of greenhouse gas (GHG) emissions on per capita income in Côte d'Ivoire by applying a multi-scale analytical framework based on wavelet methods. Over the past three decades, research on the economic consequences of climate change has expanded considerably, reflecting growing awareness of the macroeconomic challenges posed by global warming. Foundational studies by Nordhaus (1991) and Tol (2002) established the theoretical underpinnings of climate economy modeling by emphasizing the role of temperature increases and rising GHG concentrations in shaping long-term economic performance. At the global level, Dell et al. (2012) demonstrated that climate shocks particularly extreme temperatures significantly reduce GDP per capita, with stronger effects in developing countries characterized by lower adaptive capacity. These findings are consistent with earlier evidence showing that short-term temperature shocks have significant effects on income levels (Dell et al., 2009). Burke et al. (2015) further documented a nonlinear relationship between temperature and productivity, showing that tropical economies are structurally more exposed to climate-induced income losses.

These findings are highly relevant for West Africa, a region where climate vulnerability intersects with structural dependence on climate-sensitive activities such as agriculture, forestry, and fishing. In Côte d'Ivoire, climate variability manifested through irregular rainfall, extreme heat episodes, and recurrent droughts has been shown to hinder agricultural productivity, exacerbate food insecurity, and depress rural household incomes (Konan et al., 2018; Yao et al., 2020). This is consistent with early evidence showing that climatic shocks significantly reduce agricultural output across Africa (Barrios et al., 2008). Additional evidence from the United States shows that temperature fluctuations can substantially reduce agricultural output and affect overall economic performance (Deschênes and Greenstone, 2007). In addition, nonlinear evidence for Sub-Saharan Africa shows that climate change impacts sectoral output differently across industries, with some sectors significantly more vulnerable to temperature and rainfall shocks (Kutu-Adu et al., 2020). Other studies in the sub-region highlight that rainfall shocks, drought persistence, and changes in temperature patterns have broad macroeconomic effects, influencing labor productivity, commodity supply, and sectoral output (Kouadio et al., 2019; Amani and Seka, 2021). Despite their valuable insights, most of these studies rely on traditional econometric tools, such as linear regressions, cointegration tests, vector error correction models (VECM), or ARDL models. These approaches, although useful, are not well suited to capturing the nonlinear, dynamic, and multi-scale nature of interactions between climatic factors and economic outcomes.

This limitation has motivated the development of more sophisticated analytical frameworks. The Environmental Kuznets Curve (EKC) remains one of the most widely used theoretical models to examine the link between economic growth and environmental degradation. Early evidence on the Environmental Kuznets Curve also shows that environmental degradation initially rises with income before improving at higher income levels (Shafik, 1994). Originally proposed by Grossman and Krueger (1995), the EKC posits an inverted U-shaped relationship between income and pollution: environmental degradation rises during the early stages of economic development but declines once a certain income threshold is reached, owing to structural transformation, regulatory improvements, and technological innovation. Subsequent reviews have emphasized that the empirical validity of the EKC varies significantly across countries, pollutants, and time periods (Stern, 2004). Empirical support for the EKC has been mixed. Studies such as Destek and Sarkodie (2019), Koçak and Sarkgünesi (2018), and Pao and Tsai (2011) confirm the EKC hypothesis in various contexts, while others such as Halliru et al. (2020) in West Africa reject it. More recent contributions highlight the central role of industrial structure, energy composition, urbanization, and institutional quality in modulating the growth emissions nexus (Acheampong et al., 2022; Pata and Mensah, 2023; Alhassan and Kwakwa, 2023). At a global scale, Georgescu (2024) demonstrates that GDP, energy consumption, and CO_2 emissions remain structurally intertwined across both advanced and emerging economies, indicating the persistence of carbon-intensive growth worldwide.

In the West African region, the empirical evidence aligns with these global insights. Bekun and Alola (2024) show that ECOWAS countries continue to follow carbon-intensive growth trajectories despite progress in renewable energy adoption. In Côte d'Ivoire specifically, Ouattara et al. (2023) and Seka and Amani (2024) highlight the multifaceted ways through which climate variability affects the economy not only through agricultural channels but also via energy demand, infrastructure vulnerability, and total factor productivity. These findings reinforce the need for analytical methods capable of capturing complex, dynamic, and multi-scalar relationships.

To address these methodological gaps, wavelet analysis has emerged as a powerful and flexible approach for studying dynamic interactions in non-stationary time series. Introduced by Torrence and Compo (1998), wavelets allow for simultaneous decomposition of data into time and frequency domains, offering a richer understanding of cyclical behavior, structural breaks, and co-movements. Aguiar-Conraria and Soares (2011) and Gallegati et al. (2011) demonstrate that wavelet methods are particularly useful for analyzing business cycles, regime shifts, and macroeconomic synchronization. In environmental economics, Vacha and Barunik (2012) applied wavelet coherence to investigate co-movements in energy price dynamics, while Sun et al. (2020) used wavelet techniques to analyze the evolving relationship between CO_2 emissions and economic growth in China. Wavelet-based approaches have also been applied to analyze interactions between financial development, energy use, and urbanization, as shown in the case of India (Tiwari et al., 2013). Similar evidence using wavelet analysis in Africa is reported by Agboola and Bekun (2019).

More recent wavelet-based studies (2022-2025) have broadened the scope of applications. Gyamfi et al. (2022) analyzed the CO_2, GDP nexus in West Africa using wavelet coherence and found strong medium- and long-term synchronization. At the global level, Khalfaoui et al. (2023) applied wavelet coherence to G7 countries, demonstrating that the emissions growth relationship varies substantially across business cycles. Similarly, Marín-Rodríguez et al. (2023) used wavelet methods to explore dynamic connectedness among oil prices, green bonds, and CO_2 emissions, revealing complex multi-frequency transmission mechanisms. Dergiades and Tsoulfidis (2024) further show that wavelet-based causality frameworks uncover interactions and structural dependencies that traditional econometric models fail to detect.

Beyond methodological advances, the literature has documented a variety of climate-related transmission channels affecting economic performance. Kahn et al. (2021) argue that temperature increases reduce labor productivity and slow GDP growth, especially in warmer countries. Diffenbaugh and Burke (2019) provide evidence that climate change has widened global income inequalities by disproportionately affecting developing economies. Acevedo et al. (2020) identify additional channels including agriculture, human capital, infrastructure, and health through which climate shocks propagate and exert persistent effects on growth. Evidence from high-income countries also suggests strong climate–economy linkages: Colacito et al. (2018) show that temperature variability significantly reduces output in the United States, while Zhang et al. (2018) highlight that agricultural yields remain highly sensitive to climate fluctuations, with direct implications for rural income stability.

Despite the valuable insights generated by these diverse studies, no previous work has employed wavelet analysis to investigate the long-run relationship between GHG emissions and per capita income in Côte d'Ivoire**,** representing a significant empirical and methodological gap. Given the country's rapid economic transformation, structural dependence on climate-sensitive sectors, and increasing contribution to regional emissions, such an analysis is both timely and necessary.

The present study seeks to fill this gap by applying the Continuous Wavelet Transform (CWT), Cross-Wavelet Transform (XWT), and Wavelet Coherence (WTC) to explore the time–frequency dynamics linking CO_2 emissions and per capita income in Côte d'Ivoire over the period 1991-2023. More specifically, this study allows for a detailed characterization of the dynamic relationship between emissions and income.

First, it identifies the dominant cyclical patterns that shape the evolution of CO_2 emissions and per capita income over time. Second, it examines the intensity and direction of co-movements between the two variables across short-, medium-, and long-term horizons, thereby revealing how their interactions evolve at different frequencies. Third, the analysis makes it possible to detect periods during which the linkage between emissions and income becomes particularly strong or, conversely, weak and unstable. Finally, the multi-scale evidence generated by the wavelet approach provides nuanced insights that can inform the design of climate-resilient growth strategies tailored to the specific temporal dynamics of the Ivorian economy.By integrating long-term historical data with a state-of-the-art multi-scale analytical framework, this study offers new empirical evidence on the environmental growth nexus in Côte d'Ivoire and contributes meaningfully to the broader literature on climate–economy interactions in developing regions.

3. DATA AND METHODOLOGY

3.1. Data

This article examines the relationship between carbon dioxide (CO_2) emissions and per capita income in Côte d'Ivoire using continuous wavelet analysis. The annual data cover the period from 1991 to 2023 and also include methane (CH_4) emissions and agricultural value added. The main variables used are: per capita income (REV) in constant U.S. dollars, carbon dioxide (CO_2) emissions in tons per capita, methane (CH_4) emissions in CO_2 equivalent, agricultural value added (AVA) as a percentage of GDP, and urban population (URBPOP). The data are sourced from the World Bank.

3.2. Methodological Justification

The main objective of this study is to analyze the impact of climate-related variables on per capita income, while accounting for temporal dynamics and evolving multivariate relationships. The interactions between economic and environmental variables are generally non-linear, unstable, and likely to vary across different time horizons. Traditional econometric approaches (linear models, stationarity-based frameworks, ARDL, VECM, etc.) are not well-suited to capture this complexity. In response to these limitations, several authors such as Aguiar-Conraria and Soares (2011) and Gallegati et al. (2011) recommend the use of multi-scale methods like wavelet analysis, which decomposes relationships across the time–space–frequency domain, thereby capturing structural variations in economic linkages

In this context, wavelet analysis offers a significant advantage by allowing researchers to track the evolution of interactions between economic and environmental variables across different temporal scales an essential aspect for better understanding the differentiated effects of climate shocks.

3.3. Wavelet Approach

Wavelet analysis is a powerful method for exploring dynamic relationships between two time series. Unlike traditional methods, it enables the identification of local interactions both in time and frequency at short, medium, or long-term horizons, making it a particularly suitable tool for studying complex and non-stationary economic phenomena (Torrence and Compo, 1998; Rua and Nunes, 2009).

In this study, we use wavelet coherence (WTC) to measure the degree of local correlation between per capita income and the selected climate variables. This method has been employed in several recent studies to analyze unstable relationships among financial markets, energy variables, and macroeconomic indicators (Vacha and Barunik, 2012; Sun et al., 2020).

We also employ the Cross Wavelet Transform (XWT) to identify regions of high joint power between two series, highlighting the periods during which climate effects are most influential. This combined approach allows us to detect periods of synchronization or lag in the relationships under study. The interpretation of the results relies on the intensity of the colors (indicating the strength of the relationship), the direction of the arrows (indicating lead–lag or causal relationships), and the cone of influence (the confidence zone). These elements enable an intuitive and rigorous reading of the results, in accordance with the methodological guidelines proposed by Torrence and Compo (1998) and Grinsted et al. (2004).

The wavelet function can be defined as follows: Let us suppose that ψ is a square-integrable function, i.e., its Fourier transform satisfies the admissibility condition.

$\varphi(t) \in L^2(R)$

$$C_\varphi = \int_{-\infty}^{+\infty} \frac{\psi(\omega)}{\omega} d\omega < \infty \quad (1)$$

This function is then referred to as a mother wavelet or a generating wavelet function; by dilating and translating the wavelet function, we obtain the following continuous wavelet.

$$(t) = \frac{1}{\sqrt{\alpha}} \varphi\left(\frac{t-\tau}{\alpha}\right), \alpha, \tau \epsilon R, \alpha > 0 \quad (2)$$

For a national time series, the wavelet function is expressed as follows:

$$W_f(\alpha,\tau) = (f(t), \varphi_{\alpha,r}(t)) = \frac{1}{\sqrt{\alpha}} \int_{-\infty}^{+\infty} f(t) \varphi\left(\frac{(t-\tau)}{\alpha}\right) dt \quad (3)$$

For a national time series, the wavelet function is reformulated as follows:

$$(\alpha,\tau) = \sqrt{\frac{\Delta t}{\alpha}} \int_{-\infty}^{+\infty} f(t) \varphi\left(\frac{(t-\tau)}{\alpha}\right) dt \quad (4)$$

Where:
x(t) is the variable of interest (log GDP_t or log CO_{2t}).
Δt is the sampling interval (1 year, 1 quarter, etc.).
a (scale) controls the dilation;
b (translation) shifts the function over time;
φ is the mother wavelet, for example the Morlet wavelet with a central frequency ω = 6.

3.3.1. Justification for choosing the Morlet wavelet function

The mother wavelet function used in this study is the complex Morlet wavelet. This wavelet is particularly well suited for economic and environmental time series due to its ability to localize signals both in time and frequency. The Morlet wavelet combines a sinusoidal function modulated by a Gaussian envelope, giving it excellent frequency resolution while maintaining satisfactory time localization. It is therefore ideal for identifying characteristic temporal regimes, structural breaks, or medium- to long-term cycles in non-stationary data like those analyzed here. Several key studies, notably Torrence and Compo (1998) and Aguiar-Conraria and Soares (2011), recommend using this wavelet for the joint analysis of macroeconomic and environmental variables. Moreover, its standard central frequency (ω_0 = 6) provides a good balance between graphical readability and the statistical interpretation of dynamic phenomena.

Unlike traditional econometric approaches, this study adopts a multiscale analysis based on the Continuous Wavelet Transform (CWT). The strength of this method lies in its ability to explore local dynamics both in time and across multiple frequencies which is crucial for analyzing economic series that are often non-stationary. The CWT projects a time series onto a time–frequency–space domain using a mother wavelet, here the complex Morlet (cmor) wavelet. Each observation is decomposed into components at different scales, thereby revealing patterns or structural breaks in

Figure 1: Continuous wavelet transform CO_2

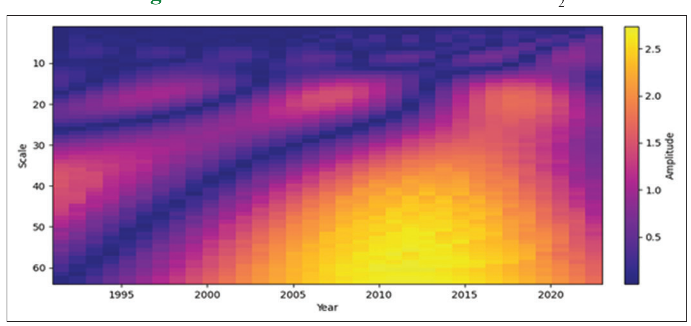
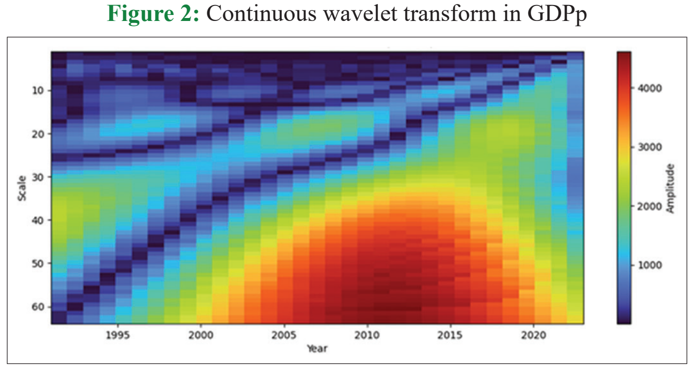


Figure 2: Continuous wavelet transform in GDPp



the series. Accordingly, we begin by applying a univariate wavelet analysis to the REV and CO_2 variables to detect the intrinsic structures of each series. Then, we perform an approximate coherence analysis using the correlation of wavelet modules at each scale to estimate the REV, CO_2 dependence.

4. INTERPRETATION OF RESULTS

4.1. Continuous Wavelet Transform

Figure 1 continuous wavelet transform (CO_2) for Côte d'Ivoire over the period 1991-2023.

The color intensity represents the amplitude of wavelet coefficients across time and scales, highlighting the dominant short-, medium-, and long-term periodicities in CO_2 emissions (Figure 1).

Figure 2 continuous wavelet transform (GDPpc) for Côte d'Ivoire over the period 1991-2023.

The color intensity represents the amplitude of wavelet coefficients across time and scales, highlighting the dominant medium- and long-term cycles in GDP per capita (Figure 2).

4.1.1. Analysis of per capita income (GDPpc)

The figure above presents the Continuous Wavelet Transform (CWT) of per capita income in Côte d'Ivoire over the period 1970-2023. This analysis highlights the evolution of the signal's spectral power over time and across different frequency scales. A significant concentration of energy (in dark red) is observed between 1998 and 2020 at scales ranging from 20 to 40. This indicates sustained medium- to long-term income dynamics, potentially reflecting the effects of prolonged economic shocks, structural reforms, or underlying macroeconomic trends. At lower scales (below 10), which correspond to short-term variations, the signal amplitude remains weak, suggesting relative stability in rapid fluctuations. In contrast, higher scales (>40) also show a decline in power, indicating a weakening of very long-term cycles.

These results confirm that per capita income in Côte d'Ivoire is primarily influenced by medium-term structural movements, which justifies the relevance of complementing the analysis with a wavelet coherence study involving climate-related and structural variables such as CO_2, CH_4, and agricultural value added.

4.1.2. Analysis of carbon dioxide (CO_2) emissions

The following figure illustrates the Continuous Wavelet Transform (CWT) applied to CO_2 emissions in Côte d'Ivoire between 1970 and 2023. It highlights the temporal and frequency dynamics of the series. A significant concentration of spectral power is observed between scales 20 and 35, mainly during the period from 2000 to 2020, indicating a sustained medium-term upward trend in emissions. This dynamic may be linked to increasing urbanization or greater reliance on fossil fuels. Conversely, amplitudes remain low at smaller scales (<10), indicating that short-term fluctuations are relatively minor. Similarly, beyond scales 45-50, the power of the signal decreases, suggesting weak long-term cyclicality. This structural evolution of CO_2 emissions supports the idea of a gradual transformation in production and consumption patterns in Côte d'Ivoire, calling for a joint analysis with economic variables.

Figure 3: Comparison of GDPpc and CO_2 trends

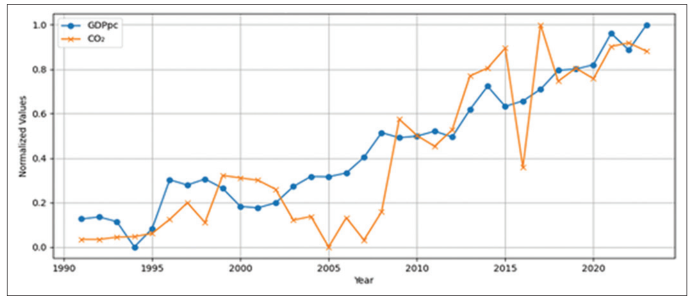
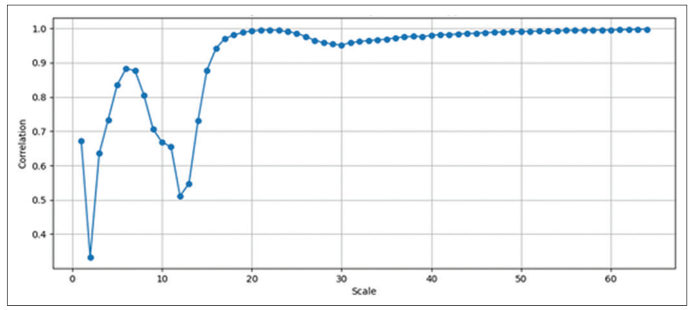


Figure 4: Correlation by scale between GDPpc and CO_2 (Approx. Coherence)



4.2. Comparative Trends in Per Capita Income and CO_2 Emissions

The graph below illustrates the joint evolution of per capita income (REV) and carbon dioxide (CO_2) emissions in Côte d'Ivoire between 1990 and 2023, following normalization of the series. It highlights a sustained increase in income beginning in the mid-1990s, with a progressive acceleration over the past two decades.

In contrast, CO_2 emissions remain relatively stable and low, suggesting an apparently low carbon intensity of economic growth, or a potential decoupling between the two phenomena at first glance. However, this exploratory analysis is insufficient to draw conclusions about the true nature of the relationship between the two variables, particularly in the presence of time lags or multi-scale effects.

To further explore this potential dynamic, we employ a wavelet coherence (WTC) analysis, which allows for the detection of time- and frequency-dependent relationships.

Figure 3 comparison of normalized GDP per capita (GDPpc) and CO_2 emissions in Côte d'Ivoire over 1991-2023.

The GDPpc series shows a strong upward trend, whereas CO_2 emissions exhibit slower and more irregular growth (Figure 3).

4.3. Wavelet Coherence between Per Capita Income and CO_2 Emissions

The figure below presents the approximate correlation between per capita income (REV) and carbon dioxide (CO_2) emissions as a function of scale, obtained through wavelet analysis. This representation makes it possible to visualize the strength of the relationship between the two variables at different frequencies (or time horizons).

It is observed that coherence is very low in the short term (scales <10), indicating the absence of an immediate link or synchronized high-frequency fluctuations. This suggests that rapid annual variations in income are not accompanied by correlated changes in CO_2 emissions.

In contrast, at medium scales (between 15 and 35), the correlation is very strong and stable, approaching 1, which reveals a robust and consistent relationship between the two variables in the medium term.

This result highlights the existence of a structural link between economic growth and emissions, which may be explained by industrialization, urban expansion, or changes in energy consumption patterns. In the long term (scales >40), coherence remains generally high but becomes more unstable, with a notable drop around scale 45. This decline could reflect changes in environmental policies, technological transitions, or the influence of other intermediate variables. These findings confirm the relevance of multi-scale analysis for detecting differentiated dynamic relationships between economic and environmental variables—relationships that are often invisible in traditional global approaches.

Figure 4 correlation by scale between GDP per capita (GDPpc) and CO_2 emissions based on the correlation of wavelet coefficients. The results show strong medium-scale coherence, indicating a persistent structural relationship between economic growth and emissions.

5. CONCLUSION AND RECOMMANDATIONS

5.1. Conclusion

This study analyzed the relationship between climate change and per capita income in Côte d'Ivoire over the period 1970-2023, using wavelet analysis as a multi-scale investigative tool. Unlike traditional econometric approaches, this method allows for the examination of both temporal and frequency dynamics in the interactions between economic and environmental variables addressing limitations often highlighted in the literature (Aguiar-Conraria and Soares, 2011; Gallegati et al., 2011).

The results reveal that per capita income exhibits strong spectral activity at medium-term scales, reflecting lasting structural influences. Similarly, CO_2 emissions also follow long-term cycles, indicating a progressive intensification of carbon-intensive economic activity. The wavelet coherence between income and CO_2 emissions confirms the existence of a strong.

These findings are consistent with the observations of Dell et al. (2012) and Burke et al. (2015), who emphasize the influence of climate change on economic performance in developing countries. They also reinforce the importance of modeling economic–environmental interactions over different time horizons. Moreover, the relationship between income and emissions observed in this study reflects the predictions of the Environmental Kuznets Curve (Grossman and Krueger, 1995; Dinda, 2004), which posits that environmental externalities increase during the early stages of development, before declining once a certain income threshold is reached.

This study thus makes an original contribution to the literature by combining a robust empirical approach with an innovative methodological framework. It highlights the importance of considering the time–frequency dimension to better understand the deep connections between the economy and the environment, particularly in a context of climate vulnerability such as that of Côte d'Ivoire.

5.2. Recommendations

In light of the empirical findings, several recommendations can be made to promote sustainable economic growth in Côte d'Ivoire while minimizing environmental impact: First, it is essential to fully integrate environmental concerns into economic development policies. The strong coherence between per capita income and CO_2 emissions in the medium term suggests that uncontrolled growth could increase the country's carbon footprint. In this regard, promoting green growth based on technological innovation, energy efficiency, and investment in renewable energy appears to be a necessary path forward. Second, the vulnerability of the agricultural sector to climate-related shocks calls for stronger adaptation policies. The government should support the modernization of agriculture through the dissemination of resilient farming practices (improved seeds, efficient irrigation, agroecology), crop diversification, and the development of social safety nets for rural populations. Third, the introduction of progressive environmental taxation could serve as an effective lever to influence the behavior of economic agents. Mechanisms such as taxes on polluting emissions, combined with tax incentives for environmentally friendly companies, would help reduce the negative externalities associated with economic activity. Fourth**,** given that wavelet analysis has revealed the complexity of dynamics across different temporal scales, it is recommended to strengthen the governance of climate and economic data. This includes improving systems for collecting, archiving, and disseminating reliable data that is disaggregated across time and space, in order to better guide public policies.

Finally, it is desirable to further promote interdisciplinary research on the interactions between environment and development. The use of time–frequency approaches, such as the one employed in this study, should be encouraged within universities, research centers, and public institutions to produce granular knowledge that is useful for decision-making.

REFERENCES

Acevedo, S., Mrkaic, M., Novta, N., Pugacheva, E., Topalova, P. (2020), The effects of Weather Shocks on Economic Activity: What are the Channels of Transmission? World Bank Working Paper.

Acheampong, A.O., Adams, S., Boateng, E. (2022), Industrial structure, institutional quality and environmental sustainability in developing countries. Energy Economics, 110, 106005.

Agboola, P.O., Bekun, F.V. (2019), Green finance and environmental sustainability in Africa: A wavelet-based analysis. Environmental Science and Pollution Research, 26(36), 35609-35622.

Aguiar-Conraria, L., Soares, M.J. (2011), The Continuous Wavelet Transform: A Primer. NIPE Working Paper.

Alhassan, H., Kwakwa, P.A. (2023), Revisiting the CO_2-growth nexus in Africa: The role of institutional quality. Journal of Environmental Management, 330, 117225.

Amani, A., Seka, M.A. (2021), Impact des variations climatiques sur la productivité agricole en Afrique de l'Ouest: Une revue empirique. Revue Économie et Développement Durable, 9(2), 45-60.

Barrios, S., Ouattara, B., Strobl, E. (2008), The impact of climatic change on agricultural production in Africa. Food Policy, 33(4), 287-298.

Bekun, F.V., Alola, A.A. (2024), Energy transition and carbon-intensive growth pathways in ECOWAS countries. Energy Policy, 187, 113743.

Burke, M., Hsiang, S.M., Miguel, E. (2015), Global non-linear effect of temperature on economic production. Nature, 527(7577), 235-239.

Colacito, R., Hoffmann, B., Phan, T. (2018), Temperature and growth: A panel analysis of the United States. Journal of Money, Credit and Banking, 50(1), 163-198.

Dell, M., Jones, B.F., Olken, B.A. (2009), Temperature and income: Reconciling new cross-sectional and panel estimates. American Economic Review, 99(2), 198-204.

Dell, M., Jones, B.F., Olken, B.A. (2012), Temperature shocks and economic growth: Evidence from the last half century. American Economic Journal: Macroeconomics, 4(3), 66-95.

Dergiades, T., Tsoulfidis, L. (2024), Multi-scale causality between economic activity and environmental variables. Energy Economics, 129, 107235.

Deschênes, O., Greenstone, M. (2007), The economic impacts of climate change: Evidence from agricultural output and random weather. American Economic Review, 97(1), 354-385.

Destek, M.A., Sarkodie, S.A. (2019), Environmental Kuznets curve hypothesis in Singapore: An empirical approach. Environmental Science and Pollution Research, 26, 30808-30817.

Diffenbaugh, N.S., Burke, M. (2019), Global warming has increased global economic inequality. PNAS, 116(20), 9808-9813.

Dinda, S. (2004), Environmental Kuznets Curve hypothesis: A survey. Ecological Economics, 49(4), 431-455.

Gallegati, M., Ramsey, J.B., Semmler, W. (2011), The US wage Phillips curve across frequencies and over time. Oxford Bulletin of Economics and Statistics, 73(4), 489-508.

Georgescu, I. (2024), Dynamic interactions between GDP, energy consumption and CO_2 emissions. Journal of Economic Structures, 13(1), 4.

Grossman, G.M., Krueger, A.B. (1995), Economic growth and the environment. The Quarterly Journal of Economics, 110(2), 353-377.

Gyamfi, B.A., Bekun, F.V., Adedoyin, F.F. (2022), Multiscale linkages between CO_2 emissions and GDP in West Africa: Wavelet coherence evidence. Environmental Research Letters, 17(7), 075012.

Kahn, M.E., Mohaddes, K., Ng, R.N.C., Pesaran, M.H., Raissi, M., Yang, J.C. (2021), Long-term macroeconomic effects of climate change: A cross-country analysis. Energy Economics, 104, 105624.

Khalfaoui, R., Tiwari, A.K., Khalid, U., Shahbaz, M. (2023), Wavelet coherence analysis of the CO_2-GDP relationship in G7 countries. Energy Economics, 122, 106684.

Konan, B.N., Kouadio, K.K., Traoré, O. (2018), Changements climatiques et rendements agricoles en Côte d'Ivoire: Une analyse économétrique. Revue Africaine de Développement Économique, 6(1), 23-42.

Kouadio, L.A., Boko, S.M., Koffi, Y.B. (2019), Variabilité climatique et croissance économique en Afrique de l'Ouest. Revue de Politique Économique et Développement, 4(2), 15-34.

Kutu-Adu, S.G., Maji, I.K., Abolade, T.S. (2020), Nonlinear effects of climate change on sectoral output in Sub-Saharan Africa. Environmental Science and Pollution Research, 27(8), 8524-8536.

Marín-Rodríguez, N.J., González-Ruiz, J., Botero, S. (2023), Dynamic connectedness among oil prices, green bonds and CO_2 emissions: A wavelet approach. Finance Research Letters, 55, 104043.

Nordhaus, W.D. (1991), To slow or not to slow: The economics of the greenhouse effect. The Economic Journal, 101(407), 920-937.

Pao, H.T., Tsai, C.M. (2011), Multivariate Granger causality between CO_2 emissions, energy consumption and economic growth in BRIC countries. Energy Policy, 38(12), 7850-7860.

Pata, U.K., Mensah, I.A. (2023), Renewable energy, institutional quality and CO_2 emissions in developing countries. Renewable Energy, 203, 300-312.

Rua, A., Nunes, L.C. (2009), International comovement of stock market returns: A wavelet analysis. Journal of Empirical Finance, 16(4), 632-649.

Seka, K., Amani, M. (2024), Climate variability and productivity in West Africa: A macro-sectoral analysis. Environmental Economics and Policy Studies. (In press).

Shafik, N. (1994), Economic development and environmental quality: An econometric analysis. Oxford Economic Papers, 46, 757-773.

Stern, D.I. (2004), The rise and fall of the environmental Kuznets curve. World Development, 32(8), 1419-1439.

Sun, X., Li, G., Ma, Y. (2020), Wavelet analysis of the relationship between CO_2 emissions and economic growth in China. Journal of Cleaner Production, 252, 119741.

Tiwari, A.K., Shahbaz, M., Islam, F. (2013), Financial development, energy consumption and urbanization in India: Wavelet decomposition analysis. Energy Policy, 61, 887-896.

Tol, R.S.J. (2002), Estimates of the damage costs of climate change. Environmental and Resource Economics, 21(1), 47-73.

Torrence, C., Compo, G.P. (1998), A practical guide to wavelet analysis. Bulletin of the American Meteorological Society, 79(1), 61-78.

Vacha, L., Barunik, J. (2012), Co-movement of energy commodities revisited: Evidence from wavelet coherence analysis. Energy Economics, 34(1), 241-247.

Yao, K.M., Koffi, N., Kouame, M. (2020), Effets des aléas climatiques sur les revenus agricoles en Côte d'Ivoire. Revue Ivoirienne d'Économie et de Gestion, 8(2), 78-96.

Zhang, P., Zhang, J., Chen, M. (2018), Economic impacts of climate change on agriculture in China. Journal of Cleaner Production, 172, 4083-4092.