Article Type: Research Paper

Unveiling the dynamics of economic growth, carbon emissions, and energy consumption in Indonesia: a wavelet analysis model

Ecky Imamul Muttaqin[1,3]*, Ganjar Primambudi[2] and Susilo Nur Aji Cokro Darsono[3]

OPEN ACCESS

AFFILIATION:
[1]Ph.D in Economics, Faculty of Economics and Business, Universitas Islam Internasional Indonesia, West Java, Indonesia

[2]Department of Economics, Kulliyyah of Economics and Management Sciences, International Islamic University Malaysia, Malaysia

[3]Department of Economics, Faculty of Economics and Business, Universitas Muhammadiyah Yogyakarta, Special Region of Yogyakarta, Indonesia

***CORRESPONDENCE**:
ecky.muttaqin@uiii.ac.id

THIS ARTICLE IS AVALILABLE IN:
http://journal.umy.ac.id/index.php/esp

DOI: 10.18196/jesp.v25i2.23136

CITATION:
Muttaqin, E. I., Primambudi, G., & Darsono, S. N. A. C. (2024). Unveiling the dynamics of economic growth, carbon emissions, and energy consumption in Indonesia: a wavelet analysis model. *Jurnal Ekonomi & Studi Pembangunan, 25*(2), 276-290.

ARTICLE HISTORY
Received:
10 Jul 2024
Revised:
21 Aug 2024
17 Sep 2024
15 Oct 2024
Accepted:
29 Oct 2024

Abstract: Climate-related economic growth has been a major topic to current economic development issues. This study tries to examine the causal relationship between economic growth, carbon emissions, and energy consumption in Indonesia using annual data from 1978 to 2022. The data is taken from the World Bank and BP-Statistical Review of World Energy. This study employs wavelet analysis to investigate the complex, time-dependent links among economic growth, carbon emissions, and energy consumption in Indonesia, offering insights into their dynamic interactions across several temporal scales. Granger causality is applied to help uncover temporal relationships and their strength, while wavelet coherence reveals frequency-specific associations across different time scales. This includes analysing cross wavelet power and cross wavelet transform. The study provides a set of research findings, economic growth in Indonesia is still supported by carbon emissions and fuel energy consumption. It shows that fossil fuels continue to dominate the economic growth engine. The consumption of coal and oil is still the leading cause of carbon emissions. This study suggests that the government should enforce consistent regulations, promote collaboration among institutions, and engage public awareness to renewable energy sources. Allocating resources to green investments and incentivizing private industry through financial instruments like carbon trading and green bonds. It can stimulate economic growth while preserving the environment. Moreover, emphasizing the long-term benefits will help establish a sustainable framework for the transition to net-zero emissions.

Keywords: Economic Growth; Emission; Energy Consumption; Wavelet Model
JEL Classification: P28; O44

Introduction

The rise of discussing sustainability issue has become a prominent aspect for regulators across country. Allen et al. (2018) reported that earth's temperature has jumped up to 0.18 degree Celsius, compared to the 1880 to 1981 period from only 0.08 degree Celsius. It indicates that the degree level of atmosphere was counted twice in a hundred year. A milestone initiated by United Nations Framework Convention on Climate Change commits to reduce GHG emission, aiming to limit global warming advancement in below 1.5 preferably to 2 degrees Celsius as compared to pre-industrial level. Consequently, it is expected to gradually be referred by other nations to meet their policy responses, dealing with future challenges related to the issue of climate change (UNFCCC, 2019).

The major cause of climate change is definitely triggered by rising greenhouse gas (GHGs) emissions in the atmosphere of the earth, which further drives to the resilience level on earth population through physical risks in the form of natural disasters and alterations of weather patterns. It also affects food and water supply as well as energy production (Gernaat et al., 2021). The United Nations has also pointed out the concept on the Seventeenth Goal of SDGs. Along with the global population continuing to grow, energy demands have risen leading to the crisis that has a detrimental impact on socio-economic aspects (Farghali et al., 2023).

There are many literature finding that since today's energy consumption is relying on fossil fuels, economic growth strongly correlates with growing in carbon emissions as mentions by Apergis & Payne (2014); Alola & Kirikkaleli (2019); Sarkodie & Owusu (2017); Adebayo et al (2021). Oil, gas, and coal account for a major share of global energy demand (Gyamfi et al., 2022; Onifade & Alola, 2022). Consequently, rising in the global energy consumption comes at a cost to the environmental degradation since it stimulates to realizing greenhouse has (GHG) emissions (Allen et al., 2018; Gyamfi et al., 2022). However, some may argue economic growth has a negative correlation with the level of GHG emissions (Doğan & Değer, 2018). Also in certain case, technological innovation may not reduce GHG emissions since fossil energy consumption is being on the top share (Onifade & Alola, 2022).

Current economic model to boost economic growth tends to be relying on industrial-based economic activities. It tremendously drives to the increase of the global energy consumption. Also it is estimated carbon dioxide emissions can reach to 37 gigatons in 2035 (Kiehbadroudinezhad et al., 2023). GHG emissions from utilizing energy production have hugely escalated among E7 economies countries over the last few decade. To illustrate, Indonesia has a huge account to the global economic share together with E7 and G7 nations, but it contributes to fast growing GHG emissions upon energy consumption utilizations (Onifade & Alola, 2022). Even though Indonesia has started to issue bio-fuels to meet energy demands, it seems to be a challenge for the government due to transition phases (Kiehbadroudinezhad et al., 2023). Therefore, this work employs wavelet analysis to reveal the dynamic, multi-scale interactions among GDP, carbon emissions, and energy sources in Indonesia, offering insights into their temporal linkages. Energy economic theory promotes greening growth will enhance environmental quality to be better. The theory also emphasizes allocations of sources for clean energy transition to encourage technological innovation as well as job opportunity. Moreover, the theory also plays a very significant role in understanding energy transition (Majeed et al., 2023). To illustrate this, reducing consumption in non-renewable energy would help small agriculture landholders and SMEs to utilize deposits in clean energy (Majeed & Mazhar, 2019). It is also supported by a study done by Frankel and Romer (1999) that consumption of conventional energy-incentive products increase due to the availability and easiest access to financial resources. On this occasion, it contributes to escalating GHG emissions, and leads to environmental degradation (Majeed et al., 2023). Energy-related CO2 emissions by sector have risen since 1990, experiencing a minor decline in 2020—probably attributable to COVID-19 response measures—but increased in 2021 as the economy recovered. The power sector accounts for 43% of CO2 emissions, making it the predominant source, followed by the transport sector at 25% and the industry sector at 23% (Climate Transparency, 2022).

Since Indonesia aspires to securing energy consumption towards sustainable economic growth, clean energy transition is required to reduce carbon emissions by promoting energy efficiency initiatives and integrating renewable energy. Consequently, a study on this topic is a very crucial topic to explore. On this occasion, the purpose of this study is to examine characteristics of national economic structure of Indonesia as it projects long term economic growth. Following this, carbon emissions mirroring capacity of energy use is very interesting topic to discuss. In addition to this, since national economic target of Indonesia is projected to expand, it might drive to endless explorations on energy resources and their capacity to produce. It is also motivated by today's share of energy production of Indonesia is still dominated by fossil fuels energy releasing carbon emissions. Thus, this study expects to bring new insights regarding energy use pattern of Indonesia ending to environmental degradation caused by carbon emissions' growth. This study contributes to the existing literature on climate-related economic development to further explore whether selected variables boost economic progress in Indonesia. This may bring insightful findings to the current study.

Research Method

This study aims to investigate the causal relationship between Economic Growth, Carbon Emissions, and Energy Consumption in Indonesia using annual data from 1978 to 2022. This time span offers a historical perspective, covering key policy moves, energy transitions, and environmental commitments, all of which are essential for providing an understanding of long-term patterns. In addition to this, it makes it possible to do a thorough causality analysis, which provides insights into the ways in which various factors influence one another. This, in turn, helps to promote sustainable development strategies and informed policymaking.

This study employs E-Views and R-Studio for data processing and analysis. The analysis will be examined using Granger Causality and Continuous Wavelet Transform (CWT) methods. Since CWT necessitates stationarity, each variable will be subjected to a unit root test (as shown in Table 3). Subsequently, the data undergoes a transformation where it is converted into a first log-difference denoted as $y_{it} = x_{it} - x_{it-1}$. To make clarity in this study, the data description and sources are provided in the given Table 1.

Table 1 Description of Variables

Variable	Description	Source
GDP *(Gross Domestic Product)*	GDP growth (percentage) value of all goods and services produced over a specific time period	World Bank
CO_2 *(Carbon Emission From Energy)*	The carbon emissions are solely from oil, gas, and coal combustion.	BP Statistical Review of World Energy
OIL *(Oil Consumption)*	Total oil consumption is taken from Inland demand, international aviation, marine bunkers, and refinery fuel and loss.	BP Statistical Review of World Energy
GAS *(Natural Gas Consumption)*	Natural Gas consumption in Exajoules converted into million-tones	BP Statistical Review of World Energy
COAL *(Coal Consumption)*	Coal consumption in Exajoules is converted into million-tonnes. Including bituminous coal, anthracite (hard coal), and lignite and brown (sub-bituminous) coal.	BP Statistical Review of World Energy

The Granger test is based on a typical bivariate dynamic structural framework, which can be described as follows, according to Thornton & Batten (1985):

$$y_t + \alpha x_t = L(\beta)^H y_{t-1} + L(\delta)^K x_{t-1} + \varepsilon_{1t} \quad (1)$$
$$x_t + \delta y_t = L(\lambda)^l x_{t-1} + L(\mu)^N y_{t-1} + \varepsilon_{2t} \quad (2)$$

x and y are jointly determined endogenous variables in the maintained structure, with $iid(0, \sigma_i^2), i = 1{,}2$ being assumed to be ε_1 and ε_2. In order to keep things simple, let $E(\varepsilon_{1t}\varepsilon_{2t'}) = 0$ for all t and t', and let $L(.)^J$ stands for the polynomial lag operator of order J, for instance, $L(\beta)^J y_{t-1} = \beta_1 y_{t-1} \beta_2 y_{t-2} + \ldots + \beta_j y_{t-j}$. The reduced form of the model is:

$$y_t = L(\pi_{11})^G y_{t-1} + L(\pi_{12})^P x_{t-1} + \mu_{1t} \quad (3)$$
$$x_t = L(\pi_{21})^G y_{t-1} + L(\pi_{22})^P x_{t-1} + \mu_{2t} \quad (4)$$

where πs are nonlinear functions of the structural parameters in (1&2), and G and P are the greater of H or N and K or l, respectively. Meanwhile, the usual formulas for the Granger version of the causality test are found in equation (3&4).

The following theories are investigated in order to look into Granger causality between x and y: $L(\pi_{12})^P = 0$ and $L(\pi_{21})^G = 0$ and B. X and y are independent series if they are both incapable of being rejected. The rejection of both indicates "feedback" between x and y. Unidirectional causation from x to y exists if the former hypothesis is rejected but the latter is not; conversely, if the latter is rejected and the former is not, the opposite is true.

Next, we follow the order of Sharif et al. (2020) to conduct Wavelet Transforms. The continuous wavelet transforms N_a (p.q) displays the projection of a wavelet ψ(.) in contrast to the time sequence a $(t) \in K^2(R), i.e.$

$$N_a(p,q) = \int_{-\infty}^{\infty} \alpha(t) \frac{1}{\sqrt{q}} \psi\left(\frac{t-p}{M}\right) \mathrm{dt} \qquad (5)$$

A crucial component of this of this method is its ability to decompose consequently and seamlessly reassemble a time series a $(t) \in K^2(R), i.e$

$$\alpha(t) = \frac{1}{C_\psi} \int_0^\infty \left[\int_{-\infty}^{\infty} N_\alpha(p,q) \psi_{p,q}(t) du\right] \frac{dq}{M^2}, M > 0 \qquad (6)$$

Additionally, this method maintains the observed time sequence's power.

$$\|\alpha\|^2 = \frac{1}{C_\psi} \int_0^\infty \left[\int_{-\infty}^{\infty} |N_\alpha(p,q)|^2 dp\right] \frac{dq}{M^2} \qquad (7)$$

The relationship between GDP, Carbon Emission, Oil Consumption, Natural Gas Consumption, and Coal Consumption can be studied across time scales using the commonly used method of wavelet coherence. This involves analysing cross wavelet power and cross wavelet transform (CWT), as defined by Torrence & Compo (1998), using two time sequences, a(t) and b(t).

$$N_{\alpha b}(p.q) = N_\alpha(p.q) N_b^*(p,q) \qquad (8)$$

Continuous transforms of time sequences a(t) and b(t) are denoted as $N_\alpha(p.q)$ and $N_b^*(p,q)$ respectively, with p and q as location indices and measures, and (*) indicating the composite conjugate. Wavelet power $|N_\alpha(p.q)\ |$ is computed using cross wavelet transform. Cross-wavelet power spectra identify regions in the time-frequency domain where strong energy concentration is observed in the investigated time series. The wavelet coherence technique (WCT) detects precise zones in the time-frequency domain where significant and unexpected changes occur in the co-movement patterns of the observed time series. The coefficient of adjusted wavelet coherence is given by an equation proposed by (Torrence & Webster, 1998).

$$W^2(p.q) \frac{\left|M\left(M^{-1} N_{\alpha b}(p,q)\right)\right|^2}{M(M^{-1}|N_\alpha(p,q)|^2) M(M^{-1}|N_b(p,q)|^2)} \qquad (9)$$

The smoothing mechanism is denoted by M. The squared wavelet coherence coefficient's range is displayed by $0 \leq W^2(p,q) \leq 1$. A high correlation is indicated by proximity to unity, whereas the absence of correlation is indicated by proximity to zero.

Result and Discussion

This section presents the findings of our analysis using Granger causality and wavelet coherence. Granger causality helps uncover temporal relationships and their strength, while wavelet coherence reveals frequency-specific associations across different time scales.

Table 2 Summary of Statistics

Indicator	GDP (Percentage)	CO2 (Million Tones)	OIL (Million Tones)	GAS (Million Tones)	COAL (Million Tones)
Mean	5.047157	281.6168	47.18449	24.98539	22.69476
Median	5.500952	264.0609	52.82891	28.37387	13.15907
Maximum	10.00000	691.9668	73.58503	39.33513	104.5810
Minimum	-13.12673	53.73849	15.43200	5.043485	0.132974
Std. Dev.	3.415772	170.7391	19.12198	11.43824	24.32902
Skewness	-3.575793	0.325104	-0.258921	-0.450039	1.194868
Kurtosis	19.31203	2.000451	1.567608	1.754289	4.169940
Jarque-Bera	594.8016	2.666003	4.349826	4.428628	13.27425
Probability	0.000000	0.263685	0.113618	0.109228	0.001311

Notes: Skewness: D'agostino (1970) test, Kurtosis: Anscombe & Glynn (1983) test, JB: Jarque & Bera (1980) normality test.

Table 2 presents the descriptive statistics for economic and environmental indicators, specifically the percentage of GDP, the amount of CO_2 in a million tons, the amount of OIL in a million tons, the amount of GAS in a million tons, and the amount of coal in a million tons.

The mean GDP stands at 5.05%, with notable fluctuations ranging from a minimum of -13.13% to a maximum of 10%. The average emission of CO_2 is around 281.62 million tons, with a positively skewed distribution (skewness = 0.33) and a flatter distribution (kurtosis = 2.00). The range of OIL production fluctuates from 15.43 million tons to 73.59 million tons, exhibiting skewness and kurtosis that are substantially similar to a normal distribution. The distributions of GAS and COAL exhibit skewness and kurtosis, suggesting a somewhat skewed pattern.

The Jarque-Bera value and its probability offer insights into the conformity of the data distribution to the normal distribution. A probability value below 0.05 (P-value < 0.05) suggests the data does not follow a normal distribution. (Jarque & Bera, 1980). Because the wavelet can only be run using stationer data, we conduct the Unit root test as seen in Table 3.

Table 3 The Augmented Dickey-Fuller (ADF) and the Phillips-Perron (PP) Unit Root Test

Variable	Level		First Difference	
	ADF	PP	ADF	PP
GDP	-4.8287***	-4.7892***	-7.2138***	-24.6220***
(Gross Domestic Product)	*0.0003*	0.0003	*0.0000*	*0.0001*
CO_2	2.4886	2.8105	-7.1808***	-2.7120*
(Carbon Emission)	*1.0000*	1.0000	*0.0000*	*0.0803*
OIL	-1.3932	-1.3943	-5.7230***	-5.2100***
(Fuel Oil Consumptions)	*0.5765*	*0.5765*	*0.0000*	*0.0001*
GAS	-1.9512	-1.9326	-5.8986***	-5.9346***
(Natural Gas Consumptions)	*0.3067*	*0.3148*	*0.0000*	*0.0000*
COAL	2.7592	3.9456	0.6115**	-3.2127**
(Coal Consumptions)	*1.0000*	*1.0000*	*0.0481*	*0.0260*

Notes: (*) Significant at the 10%; (**) Significant at the 5%; (***) Significant at the 1%. Elliott et al. (1996) unit-root test, *MacKinnon (1996) one-sided p-values.

Table 3 shows the results of unit root testing using the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) methods on the observed variables. The variable GDP indicates stationary at the level and at the first difference. CO_2, OIL, GAS, and COAL show stationary (P-value < 0,05) after being transformed to the first difference. Thus, this implies that GDP is inherently stable over time, whereas the other variables require transformation to eliminate non-stationary components. The transformation to the first difference for CO2, OIL, GAS, and COAL makes them suitable for further analysis in econometric models, ensuring that any relationships explored will be reliable and not affected by non-stationary data biases.

Table 4 Wavelet-Based Granger Causality

Frequency Domains	Dependent Variables	Independent Variaables				
		GDP	**CO_2**	**OIL**	**GAS**	**COAL**
D1	GDP	-	3.79647**	4.22953**	0.23583	0.92059
	CO_2	2.61171	-	2.06954	0.02491	1.97412
	OIL	0.84779	3.70691*	-	0.17618	5.09330**
	GAS	0.75640	2.27361	3.08039*	-	7.64792***
	COAL	1.62936	0.16606	0.21144	0.09033	-
D2	GDP	-	1.36540	1.31736	0.15984	0.37360
	CO_2	0.06467	-	1.76424	2.68728*	3.21392**
	OIL	0.19737	1.66167	-	1.08983	2.89745**
	GAS	0.36403	1.40336	1.58670	-	5.14445***
	COAL	0.89993	14.0218***	6.17364***	10.7745***	-
D3	GDP	-	0.90103	1.57804	0.07727	0.29922
	CO_2	0.03555	-	3.30558**	1.43629	5.61925***
	OIL	0.30214	1.02124	-	1.37877	1.80922
	GAS	0.23379	1.10252	0.70015	-	3.33050**
	COAL	0.53429	8.04798***	4.34356***	3.97087**	-
D4	GDP	-	0.89461	2.29902*	0.29092	0.30928
	CO_2	0.06124	-	5.06093***	1.66398	4.64281***
	OIL	0.24968	0.53869	-	1.70233	1.23110
	GAS	0.25947	1.02833	1.15776	-	4.67323***
	COAL	0.36587	6.11878***	4.39452***	3.43624**	-
D5	GDP	-	0.58618	1.93001	0.23397	0.21862
	CO_2	0.49618	-	3.92717***	3.55477***	3.74103***
	OIL	0.23625	0.46554	-	1.28691	1.07149
	GAS	0.71966	0.75041	0.99785	-	3.18711**
	COAL	0.71897	4.80485***	3.64987***	6.58242***	-

Notes: (*)Significant at the 10%; (**)Significant at the 5%; (***) Significant at the 1%

D1= using lag 1 in the granger test
D2= using lag 2 in the granger test
D3= using lag 3 in the granger test
D4= using lag 4 in the granger test
D5= using lag 5 in the granger test

Table 4 presents the results of wavelet-based Granger causality tests on various frequency domains (D1-D5) between economic and energy variables, providing comprehensive insight into cause-and-effect relationships in the system's dynamics. Lag 1 means (if it is significant): variable A has a causal relationship one year later with variable 2. Lag 5 if the relationship of variables shows significant means: variable A has a causal relationship 5 years later with variable B. This means that changes in A will have an impact on B five years later. However, in the granger causality test does not show positive or negative changes. they only show that there is a "causal relationship".

The frequency domains are structured to represent different lags, with D1 corresponding to lag 1, D2 to lag 2, D3 to lag 3, and so forth, thereby allowing for the examination of causal interactions over different time intervals. In the D1 frequency domain, there are findings that economic growth measured by GDP growth is granger caused by CO_2 emissions and OIL. In addition, at frequency D1, Oil Consumption is caused by Coal Consumption at a significant level, indicating the dependence of Coal consumption on economic dynamics and other energy sources. This result is consistent with Vo et al. (2019), but in this study, more detail on certain frequency domains and energy consumption sources.

However, in the D2 frequency domain, there is no evidence of Granger-causality of any variable to GDP, indicating a lack of causality of the energy variable on economic growth at this frequency level. On the other hand, at frequency D2, Granger-carbon dioxide (CO_2) emissions are caused by natural gas consumption (GAS) and Coal Consumption (COAL). COAL is a granger caused by CO_2, OIL, and GAS. This reflects the complexity of the interaction between carbon emission and energy consumption.

Furthermore, results on frequencies D3, D4, and D5 showed interesting variations. In D3, Granger-induced CO_2 consumption by OIL, GAS, and COAL reflects the complex causal relationship among these factors. At D4, Granger-induced GAS consumption is due to COAL, indicating the dependence of natural gas production on that energy source. At D5, Granger's CO_2 is caused by OIL, GAS and COAL. Finally, Granger's COAL caused by CO_2, OIL, and GAS in D2 until D4 provides an additional picture of the relationship between energy production and carbon dioxide emissions at lower frequency levels.

Next, wavelet coherence analysis necessitates certain guidelines to ensure accurate assessments. The research presents Time on the horizontal axis and frequency on the vertical axis, with a greater scale indicating lower frequency. The wavelet coherence is used to identify the specific areas in time-frequency space where the two-time series exhibit a mutual relationship. Warm areas (red) indicate regions with a strong correlation, whereas cold (blue) indicates weaker correlation between the series. The cold regions outside the important sections exhibit time and frequencies completely independent of the series (Thaker & Mand, 2021). The arrow in the wavelet coherence plots indicates the temporal relationship (lead or lag) between the analyzed series. A zero phase difference indicates that the two-time series exhibit synchronous movement on a specific scale. Arrows to the rightward (→) indicate in-phase or to the leftward (←) indicate anti-phase. When the two series are in phase, it signifies that they are moving in the same direction, whereas anti-phase shows that they are moving in the other way. Arrows pointing diagonally to the right-down (↘) or to the left-up (↖) indicate that the first variable is in a leading position, while arrows pointing diagonally to the right-up (↗) or to the left-down (↙) indicate that the second variable is in a leading position (Rijanto, 2023).

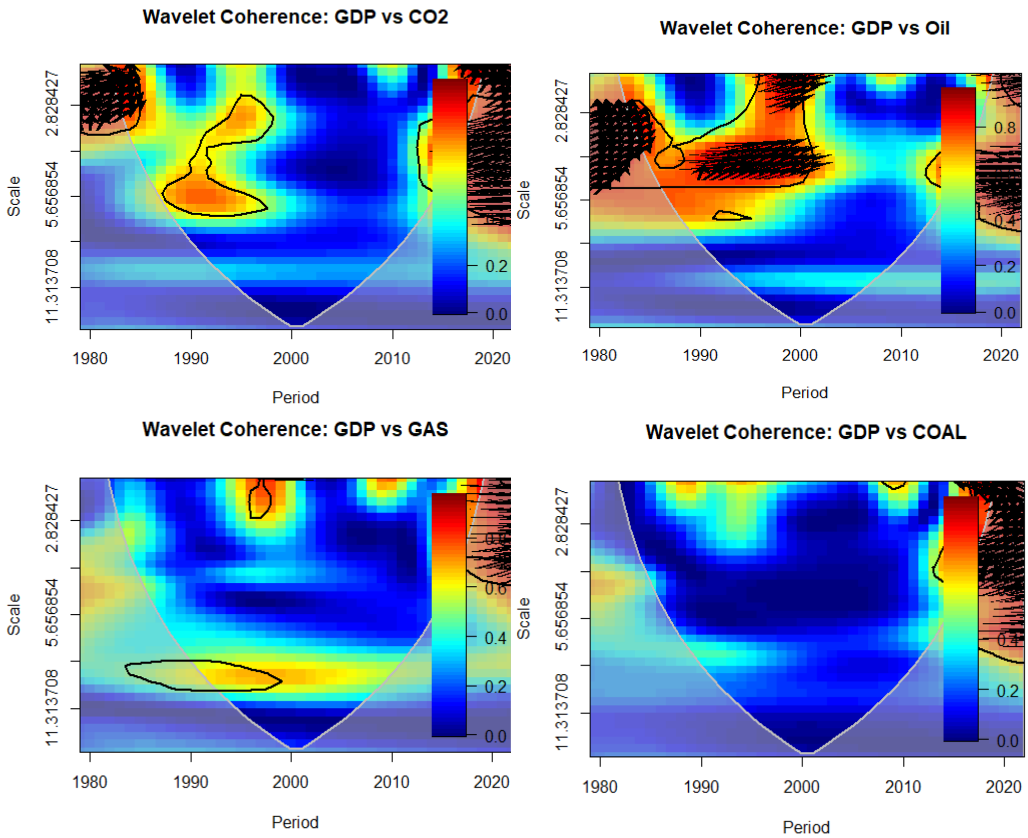

Figure 1 Wavelet Coherence Plots, Focusing on Economic Growth

Figure 1 shows wavelet coherence plots that focus more on economic growth indicators. It can be seen that carbon emissions and energy consumption definitely influence economic growth in Indonesia at different scales and different periods. Carbon emissions (CO_2) correlated closely with GDP at a low scale around the 1980s. After that, it is dominated by cold areas that have a low correlation. CO_2 became a factor of economic growth after 2010, and this can be seen from the dominance of warm areas with arrows pointing at the right-down (↘). CO_2 contributes to GDP through economic activity in household consumption, production process particularly for industry, and mobility fuel for transportation (Kusumawardhani et al., 2022; Lyazzat et al., 2023). Consumption of fossil energy that is not environmentally friendly is a trigger for increasing CO_2, as has been proven in many studies such as research by Mustafa et al. (2016), Lu (2017), Tong et al. (2020) Yuliadi & Wardani (2023). Energy consumption also contributes to economic growth, especially the intensity increased after 2010. The most significant level of wavelet coherency shows OIL as the primary contributor, followed by COAL and GAS consumption. However, the ambition of the Indonesia government to achieve Net zero emissions in 2060 must be executed carefully because it is proven that the additional improvement in renewable energy has a higher cost and lower impact on economic growth compared to non-renewable energy (Syzdykova et al., 2021; Ye et al., 2023).

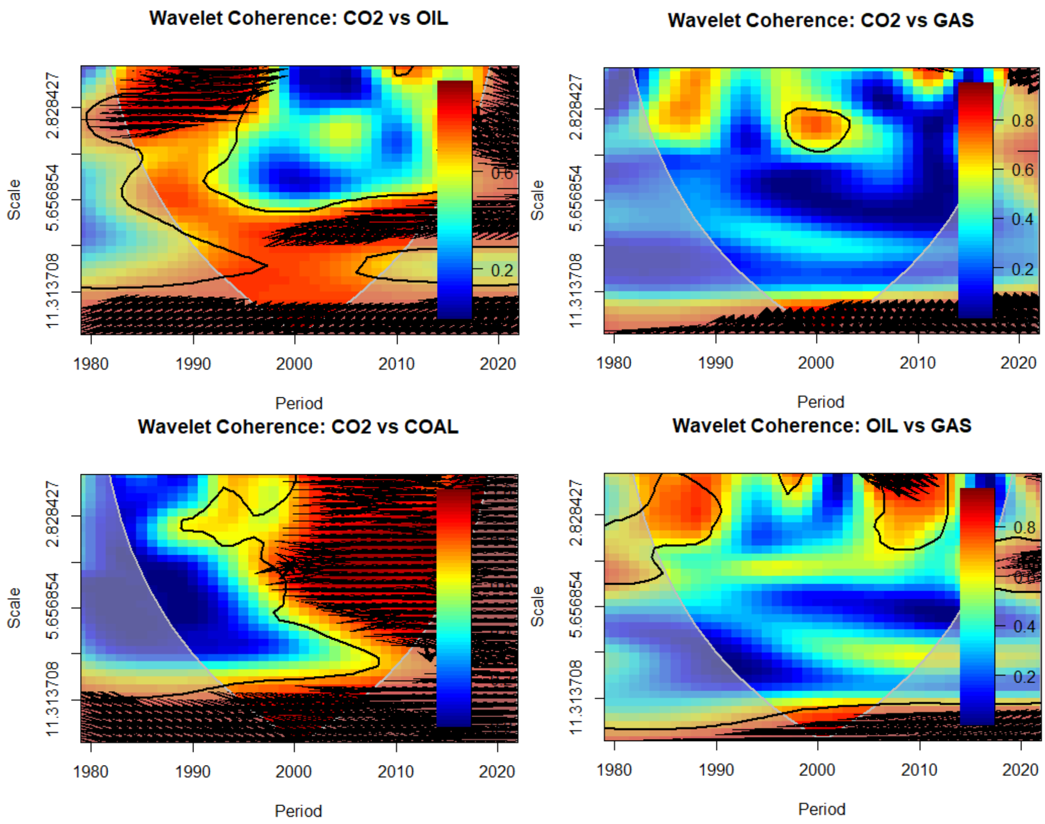

Figure 2 Wavelet Coherence Plots, Focusing on Carbon Emission

Figure 2 shows how fossil energy consumption significantly affects carbon emissions in Indonesia. It is indisputable that fossil energy consumption creates degradation and a devastating environmental impact (Purnama et al., 2020). An increase in CO_2 usually represents this adverse impact. The most considerable contribution to the increase in CO_2 has been dominated by COAL consumption since 1978. This can be seen from the dominance of warm areas in wavelet coherency. The intensity of consumption has increased on all scales since 2000. This indicates that coal is the least environmentally friendly fuel, which significantly impacts the increase in CO_2. OIL consumption is a contributor to the increase in carbon emissions after COAL. This occurs on varying scales and lasts throughout the observation period. This is reasonable because locomotives driving vehicles and industry are still dominated by fuel oil. In line with research by Farabi et al. (2019), GAS became a less contributor to CO_2. It is characterized by the dominance of cold areas in the cone, but beyond that, it increased on a higher scale, especially after 1990.

Wavelet coherency between energy consumption variables is also interesting to discuss. The coherence of OIL and GAS consumption is aimed at different variations. OIL, the leading variable of COAL consumption, is aimed with a left-up (↖) arrow. Mining oil consumption will also encourage gas consumption to increase. The extensive use of non-renewable energy is the primary source of increasing air pollution (CO_2) due to hazardous fossil fuel emissions. Considering the undeniable impact of energy on economic growth, it has become crucial to separate harmful greenhouse gas emissions from a country's development in order to achieve sustainable goals (Saudi et al., 2019).

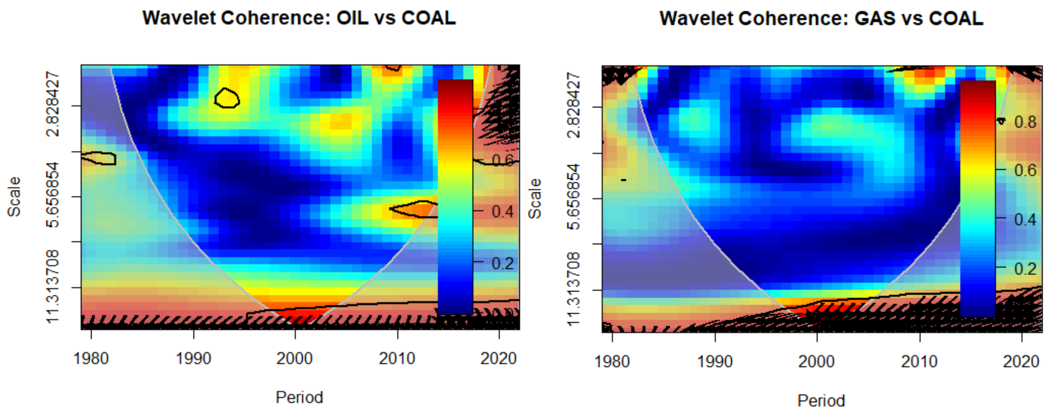

Figure 3 Wavelet Coherence Plots, Focusing on Energy Consumption

Oil and gas consumption is influenced by coal consumption. This can be seen in the direction of the right-up (↗) arrow on OIL and left-down (↙) on GAS. These two energy sources have strong coherency on higher scales and have a long observation period (since 1978). Cold areas (blue) continue to dominate at lower scales, especially inside the cone, indicating a low level of coherency. The government encourages the sifting from non-renewable energy to renewable energy, which is one of the main goals of transformation. However, financing and technological factors are the main obstacles to slow progress (Lieu & Ngoc, 2023).

The government must adhere to regulations consistently, foster cooperation across institutions, and prioritize ongoing public engagement (Priyagus, 2021). Moreover, the government should allocate its resources, both in terms of energy and financial institutions, towards green investments and exploiting environmentally friendly energy (Fitriyah, 2019). This can be done by encouraging private industry and providing financial instruments such as carbon trading and green bonds (Elfaki & Heriqbaldi, 2023; Taridala et al., 2023). This is undeniably beneficial for promoting investment and attaining enhanced economic growth through preserving a high-quality environment over an extended period.

Conclusion

This research concludes that economic growth in Indonesia is still supported by carbon emissions and fuel energy consumption. This result demonstrates that environmentally unfriendly fuels continue to dominate the economic growth engine. The consumption of coal and oil is still the leading cause of carbon emissions. This challenge must be analysed when Indonesia has an emissions-free policy ambition by shifting fossil energy consumption to renewable energy. If not appropriately calculated, this transition process will harm Indonesia's ability to achieve its economic growth target. The primary step is to reduce CO2 by focusing on shifting coal consumption to other environmentally friendly energy sources. Furthermore, oil consumption needs to be reduced carefully.

This study suggested that the government should enforce consistent regulations, promote collaboration among institutions, and engage the public. Allocating resources to green investments and incentivizing private industry through financial instruments like carbon trading and green bonds. It can trigger economic growth while preserving the environment. Emphasizing the long-term benefits will help establish a sustainable framework for the transition to net-zero emissions. This study contributes to, firstly, the wavelet model shows how economic growth, carbon emissions, and energy consumption change over time. This knowledge can help identify optimal intervention times. Secondly, the investigation can determine if economic expansion drives energy demand or energy use raises carbon emissions. This knowledge is essential for focused regulation. The study can help policymakers weigh economic development and environmental sustainability. It can help create green energy solutions that boost economic growth. Thirdly, the study may clarify how different Indonesian regions experience similar patterns, enabling tailored regional approaches to address local concerns. The study can fill gaps in the literature on these factors' interactions in Indonesia by using wavelet analysis, a novel methodological approach that future researchers can duplicate.

Author Contributions

Conceptualisation, E.I.M. and G.P.; Methodology, G.P.; Investigation, G.P; Analysis, G.P. and E.I.M.; Original draft preparation, S.N.A.C.D. and E.I.M; Review and editing, E.I.M. and S.N.A.C.D.; Visualization, G.P.

Conflicts of Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

References

Allen, M., Babiker, M., & Chen, Y. (2018). Global Warming of 1.5°C: An IPCC Special Report on Impacts of Global Warming of 1.5°C above Pre-industrial Levels in Context of Strengthening Response to Climate Change, Sustainable Development, and Efforts to Eradicate Pover. *Global Warming of 1.5°C*, 1–24. https://www.cambridge.org/core/product/identifier/9781009157940%23prf2/type/book_part

Alola, A. A., & Kirikkaleli, D. (2019). The nexus of environmental quality with renewable consumption, immigration, and healthcare in the US: wavelet and gradual-shift causality approaches. *Environmental Science and Pollution Research*, *26*(34), 35208–35217.

https://doi.org/10.1007/s11356-019-06522-y

Anscombe, F. J., & Glynn, W. J. (1983). Distribution of the kurtosis statistic b2 for normal samples. *Biometrika*, *70*(1), 227–234. https://doi.org/10.1093/biomet/70.1.227

Climate Transparency (2022). Climate Transparency Report: Comparing G20 Climate Action. https://www.climate-transparency.org/wp-content/uploads/2022/10/CT2022-Indonesia-Web.pdf

D'agostino, R. B. (1970). Transformation to normality of the null distribution of g1. *Biometrika*, *57*(3), 679–681. https://doi.org/10.1093/biomet/57.3.679

Doğan, B., & Değer, O. (2018). The energy consumption and economic growth in the E7 countries: Cointegration in panel data with structural breaks. *Romanian Journal of Economic Forecasting*, *21*(1), 63–75.

Elfaki, K. E., & Heriqbaldi, U. (2023). Analyzing the Moderating Role of Industrialization on the Environmental Kuznets Curve (EKC) in Indonesia: What Are the Contributions of Financial Development, Energy Consumption, and Economic Growth? *Sustainability (Switzerland)*, *15*(5). https://doi.org/10.3390/su15054270

Elliott, G., Rothenberg, T. J., & Stock, J. H. (1996). EFFICIENT TESTS FOR AN AUTOREGRESSIVE UNIT ROOT. *Econometrica*, *64*(4), 1–21. https://doi.org/https://doi.org/10.2307/2171846

Farabi, A., Abdullah, A., & Setianto, R. H. (2019). Energy consumption, carbon emissions and economic growth in Indonesia and Malaysia. *International Journal of Energy Economics and Policy*, *9*(3), 338–345. https://doi.org/10.32479/ijeep.6573

Farghali, M., Osman, A. I., Mohamed, I. M. A., Chen, Z., Chen, L., Ihara, I., Yap, P. S., & Rooney, D. W. (2023). Strategies to save energy in the context of the energy crisis: a review. In *Environmental Chemistry Letters* (Vol. 21, Issue 4). Springer International Publishing. https://doi.org/10.1007/s10311-023-01591-5

Fitriyah, N. (2019). Financial development and environmental degradation in indonesia: Evidence from auto regressive distributed lag bound testing method. *International Journal of Energy Economics and Policy*, *9*(5), 394–400. https://doi.org/10.32479/ijeep.8286

Frankel, J. A., & Romer, D. (1999). Does Trade Cause Growth? *Global Trade*, *1991*, 255–275. https://doi.org/10.4324/9781315254166-11

Gernaat, D. E. H. J., de Boer, H. S., Daioglou, V., Yalew, S. G., Müller, C., & van Vuuren, D. P. (2021). Climate change impacts on renewable energy supply. *Nature Climate Change*, *11*(2), 119–125. https://doi.org/10.1038/s41558-020-00949-9

Gyamfi, B. A., Ampomah, A. B., Bekun, F. V., & Asongu, S. A. (2022). Can information and communication technology and institutional quality help mitigate climate change in E7 economies? An environmental Kuznets curve extension. *Journal of Economic Structures*, *11*(1). https://doi.org/10.1186/s40008-022-00273-9

Jarque, C. M., & Bera, A. K. (1980). Efficient tests for normality, homoscedasticity and serial independence of regression residuals. *Economics Letters*, *6*(3), 255–259. https://doi.org/10.1016/0165-1765(80)90024-5

Kiehbadroudinezhad, M., Merabet, A., Ghenai, C., Abo-Khalil, A. G., & Salameh, T. (2023). The role of biofuels for sustainable MicrogridsF: A path towards carbon neutrality and the green economy. *Heliyon*, *9*(2), e13407. https://doi.org/10.1016/j.heliyon.2023.e13407

Kusumawardhani, H. A., Susilowati, I., Hadiyanto, & Melati, F. C. (2022). Analysis of Environmental Degradation in Indonesia Based on Value Added Industry, Economic Growth, and Energy Consumption. *International Journal of Sustainable Development and Planning*, *17*(6), 1721–1726. https://doi.org/10.18280/ijsdp.170605

Lieu, P. T., & Ngoc, B. H. (2023). The relationship between economic diversification and carbon emissions in developing countries. *International Journal of Applied Economics, Finance* *and Accounting*, *15*(1), 21–28. https://doi.org/10.33094/ijaefa.v15i1.747

Lu, W. C. (2017). Greenhouse gas emissions, energy consumption and economic growth: A panel cointegration analysis for 16 Asian countries. *International Journal of Environmental Research and Public Health*, *14*(11). https://doi.org/10.3390/ijerph14111436

Lyazzat, K., Abubakirova, A., Igilikovna, O. A., Zhanargul, T., & Suleimenovna, S. B. (2023). The Relationship between Energy Consumption, Carbon Emissions and Economic Growth in ASEAN-5 Countries. *International Journal of Energy Economics and Policy*, *13*(2), 265–271. https://doi.org/10.32479/ijeep.13980

MacKinnon, J. G. (1996). Numerical Distribution Functions for Unit Root and Cointegration Tests. *Journal of Applied Econometrics*, *11*(6), 601–618. http://www.jstor.org/stable/2285154

Majeed, M. T., & Mazhar, M. (2019). Financial development and ecological footprint: A global panel data analysis. *Pakistan Journal of Commerce and Social Science*, *13*(2), 487–514.

Majeed, M. T., Mazhar, M., & Hussain, Z. (2023). Environmental Impact of Digital Financial Inclusion and Green Growth: Insights from Global Panel Data Analysis. *Pakistan Journal of Commerce and Social Science*, *17*(3), 558–587.

Mustafa, G., Latif, I. A., Shah, S. Z., & Bashir, M. K. (2016). Nexus between CO2 emission, energy consumption and economic growth in ASEAN countries plus China. *American Journal of Environmental Sciences*, *12*(4), 299–307. https://doi.org/10.3844/ajessp.2016.299.307

Onifade, S. T., & Alola, A. A. (2022). Energy transition and environmental quality prospects in leading emerging economies: The role of environmental-related technological innovation. *Sustainable Development*, *30*(6), 1766–1778. https://doi.org/10.1002/sd.2346

Priyagus, P. (2021). Does economic growth efficient and environmental safety? The case of transportation sector in Indonesia. *International Journal of Energy Economics and Policy*, *11*(6), 365–372. https://doi.org/10.32479/ijeep.11807

Purnama, H., Gunarto, T., & Budiarty, I. (2020). Effects of energy consumption, economic growth and urbanization on indonesian environmental quality. *International Journal of Energy Economics and Policy*, *10*(6), 580–587. https://doi.org/10.32479/ijeep.10586

Radmehr, R., Ali, E. B., Shayanmehr, S., Saghaian, S., Darbandi, E., Agbozo, E., & Sarkodie, S. A. (2022). Assessing the Global Drivers of Sustained Economic Development: The Role of Trade Openness, Financial Development, and FDI. *Sustainability (Switzerland)*, *14*(21). https://doi.org/10.3390/su142114023

Rijanto, A. (2023). Co-Movements between an Asian Technology Stock Index and Cryptocurrencies during the COVID-19 Pandemic: A Bi-Wavelet Approach. *Economies*, *11*(9). https://doi.org/10.3390/economies11090232

Saudi, M. H. M., Sinaga, O., Roespinoedji, D., & Razimi, M. S. A. (2019). The role of renewable, non-renewable electricity consumption and carbon emission in development in Indonesia: Evidence from distributed lag tests. *International Journal of Energy Economics and Policy*, *9*(3), 46–52. https://doi.org/10.32479/ijeep.7730

Sharif, A., Aloui, C., & Yarovaya, L. (2020). COVID-19 pandemic, oil prices, stock market, geopolitical risk and policy uncertainty nexus in the US economy: Fresh evidence from the wavelet-based approach. *International Review of Financial Analysis*, *70*. https://doi.org/10.1016/j.irfa.2020.101496

Syzdykova, A., Abubakirova, A., Erdal, F. B., Saparova, A., & Zhetibayev, Z. (2021). Analysis of the relationship between renewable energy and economic growth in selected developing countries. *International Journal of Energy Economics and Policy*, *11*(1), 110–116. https://doi.org/10.32479/ijeep.10397

Taridala, S. A. A., Alzarliani, W. O., Fauziyah, E., Rianse, I. S., & Arimbawa, P. (2023). Green Finance, Innovation, Agriculture Finance and Sustainable Economic Development:

The Case of Indonesia's Provincial Carbon Emissions. *International Journal of Energy Economics and Policy*, *13*(1), 271–280. https://doi.org/10.32479/ijeep.13959

Thaker, H. M. T., & Mand, A. A. (2021). Bitcoin and stock markets: a revisit of relationship. *Journal of Derivatives and Quantitative Studies*, *29*(3), 234–256. https://doi.org/10.1108/JDQS-07-2020-0016

Thornton, D. L., & Batten, D. S. (1985). Lag-Length Selection and Tests of Granger Causality Between Money and Income. *Journal of Money, Credit and Banking*, *17*(2), 164. https://doi.org/10.2307/1992331

Tong, T., Ortiz, J., Xu, C., & Li, F. (2020). Economic growth, energy consumption, and carbon dioxide emissions in the E7 countries: A bootstrap ARDL bound test. *Energy, Sustainability and Society*, *10*(1). https://doi.org/10.1186/s13705-020-00253-6

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<0061:apgtwa>2.0.co;2

Torrence, C., & Webster, P. J. (1998). The annual cycle of persistence in the El Nño/Southern Oscillation. *Quarterly Journal of the Royal Meteorological Society*, *124*(550), 1985–2004. https://doi.org/10.1002/qj.49712455010

UNFCCC. (2019). *Roadmap to US$100 Billion*. 1–25. https://unfccc.int/sites/default/files/resource/climate-finance-roadmap-to-us100-billion.pdf

Vo, A. T., Vo, D. H., & Le, Q. T.-T. (2019). CO2 Emissions, Energy Consumption, and Economic Growth: New Evidence in the ASEAN Countries. *Journal of Risk and Financial Management*, *12*(3), 145. https://doi.org/10.3390/jrfm12030145

Ye, N., Yuan, L., & Xu, Y. (2023). Non-parametric research methods to measure energy efficiency and renewable energy nexus: evidence from emerging economies. *Economic Research-Ekonomska Istraživanja* , *36*(1), 2421–2442. https://doi.org/10.1080/1331677X.2022.2097448

Yuliadi, I., & Wardani, D. T. K. (2023). Macroeconomic Variables and Its Impact on CO2Emissions: An Empirical Study on Selected ASEAN Economic Community (AEC) Countries. *International Journal of Sustainable Development and Planning*, *18*(1), 139–144. https://doi.org/10.18280/ijsdp.180114