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Economic growth, carbon dioxide emissions and energy consumption in Algeria: a wavelet coherence approach

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Abstract

Purpose – The world is nowadays facing major environmental damage and climate change everywhere. Carbon dioxide emissions are major causes of such change. It is in this respect that the current study provides a fresh insight into the dynamic nexus between energy consumption (EC), economic growth (EG) and CO_2 emissions in Algeria, as it is considered as one of the top CO_2 emitters in Africa.

Design/methodology/approach – The authors use the wavelet approaches and Breitung and Candelon (2006) causality test to gauge the association between EC, EG and CO_2 emissions over the period 1971–2018. Specifically, this study implements the wavelet power spectrum (WPS) to identify the power and variability of each variable at different time scales. The wavelet coherence, phase differences and partial wavelet coherence are also used to assess the co-movement and lead lag relationship between economic growth, energy consumption and CO_2 emissions over different time scale. Finally, Breitung and Candelon (2006) causality test is used to find the causality among variables.

Findings – The wavelet power spectrum results indicate that economic growth, energy consumption and CO_2 emissions share common strong variance in the medium and long run. Furthermore, the wavelet coherence results suggest that there is a significant co-movement between EG and CO_2 emissions, and EG is the leading variable for CO_2 emissions and EC. The results also unveil that both EG and EC cause CO_2 emissions both in short and long run. The results suggest that Algeria should take suitable measures towards the promotion of renewable energy sources.

Originality/value – The present empirical study filled the literature gap of applying the wavelet approach and frequency domain spectral causality test to examine this relevant issue for Algeria.

Keywords Energy consumption, CO_2 emissions, Economic growth, Wavelet coherence, Partial wavelet coherence, Algeria

Paper type Research paper

1. Introduction

Carbon dioxide (CO_2) is the main greenhouse gas responsible for about three-quarters of emissions (National Geographic, 2020). According to the International Panel on Climate Change, rising level of carbon dioxide emissions (CO_2) is a primary contributor to climate instability and global warming. With the growing public awareness of the negative impact of CO_2 emissions on the environment, various global agreements have been adopted to tackle this issue. The Paris Agreement is the most recent global commitment to address climate change and its negative impacts. The agreement coordinated international efforts to keep the temperature rise well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C (United Nations Climate Change, 2020). To meet these targets, the agreement requires reaching net zero CO_2 emissions by 2050.

JEL Classification — C5, J11, O4, Q5
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According to International Energy Agency (2019), the increase in CO_2 emissions is driven mainly by higher energy consumption resulting from a robust economic growth. Meanwhile, economic growth and a large consumption of energy are the main reasons why carbon dioxide emissions and other greenhouse gases increased. Therefore, a number of empirical researches have investigated the relationship amongst energy consumption, economic growth and CO_2 emissions in both developing and developed countries. In fact, results of researches on the nexus between economic growth, energy consumption and CO_2 emissions do not produce the same conclusions. Some researchers attribute the difference in the results of these studies to the statistical methods used for estimation (Omri, 2013; Khochiani and Nademi, 2020). In view of this, the present study seeks to contribute to this strand of the literature by analysing the interaction between EG, EC and CO_2 emissions for Algeria using a relatively new technique, namely, the wavelet approach. Wavelet analysis is a time and frequency domain technique. The advantage of the wavelets technique over standard time series econometrics methods, and spectral analysis is its ability to uncover the co-movement between variables at frequency and time dimensions simultaneously (Tastan and Sahin, 2020). Wavelet coherency and phase differences techniques are useful tools to analyse the causalities among the variables in both time scales and frequency bands. At the same time, the direction of the causality between the variables can also be identified at different moments in time. Besides, an important advantage of wavelet analysis is the ability to control for potential nonlinearity and structural breaks in the relationship between the two variables (Aguiar-Conraria *et al.*, 2008; Antonakakis *et al.*, 2018).

In fact, Algeria is the second largest emitter of carbon dioxide in Africa. CO_2 emissions per capita increased from 2.83 metric tons in 2000 to 3.7 metric tons in 2016. While in neighbouring Morocco, which has nearly the same number of populations, CO_2 emissions increased from 1.3 metric tons in 2000 to 1.74 metric tons in 2016 (World Bank, 2020). Furthermore, the Algerian economy has witnessed significant increase in the level of energy consumption in recent years. The level of energy consumption per capita in Algeria increased from 867.8 Kilograms of oil equivalent in 2000 to 1327.54 KGOE in 2014 while in Morocco, it was 554.14 KGOE in 2014 (World Bank, 2020). Compared to other developing countries with a similar development level (for example Morocco), Algeria's energy consumption is relatively high. This is, first, due to the fact that Algeria is an oil exporting country, and the fuel prices in the country are heavily subsidized. So, appropriate policy options are highly needed to meet the country's commitment towards reducing its greenhouse gas emissions 7% from business as usual by 2030. Therefore, achieving this goal will involve understanding driving factors behind carbon emissions in Algeria.

In this perspective, the present paper employs the wavelet approach and the frequency domain causality test for examining the relationship between economic growth, energy consumption and CO_2 emissions in Algeria. The contribution of this paper is to investigate the nexus amongst these variables for Algeria using a relatively new econometrics technique to provide robust information about this link.

The study is structured as follows: the second section summarises the literature review. Section three presents the estimation methodology, as for the fourth section, it discusses the empirical results. Finally, section five provides the general conclusion.

2. Literature review

The empirical literature that examined the connections among energy consumption, economic growth and carbon dioxide emission can be categorized into four strands of empirical researches.

The first set of empirical research focuses on the linkage between energy consumption and economic growth. The first research in this topic was conducted by Kraft and Kraft (1978) for the United States. Thereafter, numerous studies have investigated this topic (Erol and Yu, 1987; Asafu-Adjaye, 2000; Soytas and Sari, 2006; Adewuyi and Awodumi, 2017; Shahbaz *et al.*, 2017; Sarwar *et al.*, 2017; Yıldırım *et al.*, 2019; Rehman *et al.*, 2019). However, the empirical outcomes of studies in this issue have been mixed and controversial for both developed and developing countries.

The second category of research examines the existence of the Environmental Kuznets Curve (EKC) hypothesis between economic growth and carbon dioxide emissions. These studies reach conflicting conclusions about CO_2/GDP relation. The EKC has been confirmed in Selden and Song (1994), Fujii and Managi (2013), Shahbaz *et al.* (2013), Wang and Liu (2017) and He *et al.* (2017). Yet, the validity of the EKC hypothesis has been rejected by Pao and Tsai (2011), Ozcan (2013) and Robalino-López *et al.* (2015).

The third category of research focuses on the relationship between energy consumption and carbon emissions. It has also found that energy consumption is, so far, the largest source of CO_2 emissions in the world. The nexus between energy consumption and CO_2 emissions has been investigated by numerous studies (e.g. Zhang and Cheng, 2009; Soytas and Sari, 2009; Alkhathlan and Javid, 2015; Ahmad *et al.*, 2016; Saidi and Mbarek, 2016 and Tiba and Omri, 2017). The outcomes have reported mix findings.

Another strand of researchers examined the nexus between economic growth, energy consumption and CO_2 emissions by considering them simultaneously in a modelling framework. The studies on the relationship between these three variables have produced mix results. Varied findings are mainly for the use of different data set and different econometric techniques (Waheed *et al.*, 2019). Some studies have used traditional econometric techniques like the autoregressive distributed lag (ARDL) bounds test, Johansen co-integration VECM, two-regime threshold co-integration model, panel data models, multivariate co-integration models, granger causality test, Toda-Yamamoto procedure and simultaneous equations model. For instance, in case study of China, Chang (2010) examined the causality of carbon dioxide emissions, energy consumption and economic growth using a multivariate co-integration causality tests. The author has found a bidirectional causality relationship between GDP, CO_2 emissions and energy consumption and a feedback causality between energy consumption and CO_2 emissions. Using the STIRPAT model and provincial panel data from 1995 to 2010 in China, Zhang and Lin (2012) have shown that urbanization increases energy consumption and CO_2 emissions. Similarly, Wang *et al.* (2016) have found a bidirectional causal relationship between economic growth and energy consumption and a unidirectional causality running from energy consumption to CO_2 emissions. In case study of India, Tiwari (2011) has found that CO_2 emissions have a positive impact on energy consumption and negative impact on GDP, while energy consumption has positive impact on both CO_2 emissions and GDP. In a more recent study, Banday and Aneja (2019) investigated the relationship between energy consumption, economic growth and CO_2 emissions for the G7 countries and found a significant causal link from renewable energy to carbon emission for France, Italy, Japan and UK, whereas no causal relationship for Canada, Germany and USA.

For the MENA region, we identify several studies by Arouri *et al.* (2012), Omri (2013), Alshehry and Belloumi (2015) and Salahuddin and Gow (2014). For instance, Arouri *et al.* (2012) employed panel co-integration techniques to analyse the link amongst carbon dioxide emissions, energy consumption and real GDP for 12 MENA countries during the period of 1981–2005. Results have shown that energy consumption has a positive significant impact on CO_2 emissions. Omri (2013) examines the interaction between CO_2 emissions, energy consumption and economic growth by implementing a simultaneous-equations panel models for 14 countries from the MENA region over the period 1990–2011. He has found a bidirectional causal relationship between energy consumption and economic growth and a unidirectional causality from energy consumption to CO_2 emissions. Also, has found a bidirectional causal relationship between economic growth and pollutant emissions. Using the Johansen multivariate co-integration approach, Alshehry and Belloumi (2015), studied the causal relationships between energy consumption, energy price and economic activity for Saudi Arabia over the period 1971–2010. The authors incorporated CO_2 emissions as a control variable and found a long-run unidirectional causality stands from energy consumption to economic growth and CO_2 emissions, bidirectional causality between carbon dioxide emissions and economic growth and a long-run unidirectional causality runs from energy price to economic growth and CO_2 emissions. Salahuddin and Gow (2014), in a study on GCC countries, identified a positive and significant association between energy consumption and CO_2 emissions and between economic growth and energy consumption. However, regarding GDP-CO_2 emissions nexus no significant relationship was found.

Furthermore, a handful recent empirical studies have used the wavelet coherence methods to consider the relationship between energy consumption, CO_2 emissions and economic growth (Jammazi and Aloui, 2015; Bilgili *et al.*, 2016; Khochiani and Nademi, 2020). For instance, Jammazi and Aloui (2015) investigate the link between energy consumption, CO_2 emissions and economic growth for six GCC countries over the period 1980–2013 by using wavelet coherence and a wavelet window cross correlation (WWCC) technique. They uncover the existence of bilateral causal effects between energy consumption and economic growth, and a unidirectional causality stands from energy consumption to CO_2 emissions. In a similar vein, Bilgili *et al.* (2016) explore the nexus between biomass consumption and CO_2 emissions in the United States applying the continuous wavelet coherency and phase differences. Their results show that biomass consumption lowers CO_2 emissions in the long run cycles after the year 2005. In a more recent study, Khochiani and Nademi (2020) assessed the relationship between energy consumption, CO_2 emissions and economic growth in the United States, China and India by applying the wavelet correlation and the partial wavelet coherence approach over the period 1971–2013. In their study, the authors observed a positive correlation amongst GDP, CO_2 emissions and energy consumption over these three polluting countries.

In the case of Algeria, there are a few published papers which have focused on the interactive linkage between energy consumption, CO_2 emissions and economic growth. For instance, Bouznit and Pablo-Romero (2016) analysed the relationship between CO_2 emissions, energy use and economic growth in Algeria over the period 1970–2016. The authors found that an increase in energy use and electricity consumption increase CO_2 emissions. Moreover, their results confirm the EKC for Algeria. The EKC hypothesis was also confirmed by Lemtaouch (2017), who estimated the EKC model for Algeria during the period 1907–2013. Whereas, Lacheheb *et al.* (2015) found that the EKC does not exist for Algeria over the period 1971–2009. In the same vein, Sari Hassoun *et al.* (2018) investigated the nexus amongst renewable energy, economic growth and CO_2 emissions in Algeria over the period 1995–2016 and found that an increase in GDP and energy consumption upsurge the level of carbon emissions. Amri (2017) identified the linkage between nonrenewable energy consumption, renewable energy consumption, economic growth and CO_2 emissions in Algeria during 1980–2011. Hence, the results indicated the validity of the EKC hypothesis. Moreover, the ARDL with break point method outcome demonstrates that nonrenewable energy consumption in Algeria contributes to environmental degradation. Chekouri *et al.* (2020) used the STIRPAT model to analyse the impacts of population, urbanization, affluence and energy use on carbon dioxide emissions in Algeria from 1971 to 2016 using the PLS regressions approach. They found that population is the major factor behind increasing CO_2 emissions in Algeria, followed by energy use, urbanization and affluence (GDP per capita). They concluded that the EKC hypothesis does not hold in the case of Algeria.

However, to the best of our knowledge, none of the abovementioned studies have used the wavelet analysis tools to gauge the association between energy consumption, economic growth and CO_2 emissions in Algeria. Specifically, this study uses the wavelet power spectrum (WPS) to identify the power and variability of each variable at different time scales.

The wavelet coherence, phase differences and partial wavelet coherence are also used to assess the co-movement and lead lag relationship between economic growth, energy consumption and CO_2 emissions over different time scale. Finally, Breitung and Candelon (2006) causality test is used to find the causality among variables.

3. Methodology

3.1 The continuous wavelet transform (CWT)

Wavelet methods are relatively new tools to analyse non-linear and non-stationary economic and financial data. They have their roots in Fourier analysis, but overcome limitations of this method (Masset, 2015). The wavelet analysis has some advantages over Fourier method, as it combines information from both time and frequency domains simultaneously (Tastan and Sahin, 2020).

The continuous wavelet transform (CWT) is widely used for wavelet analysis and is a powerful mathematical tool for analysing non-stationary time series in the time-frequency domain.

For a time series $x(t)$ the continuous wavelet transform (CWT) for wavelet $\psi(t)$ is defined as:

$$w_{x,\psi}(\tau, s) = \int_{-\infty}^{+\infty} x(t) \frac{1}{\sqrt{|s|}} \psi^* \left(\frac{t-\tau}{s} \right) dt \tag{1}$$

Where: τ and s indicate the time and the frequency domain of the wavelet, respectively.

$\psi(t)$ is Morlet wavelet function, which is given as:

$$\psi(t) = \pi^{-\frac{1}{4}} \exp(i\varpi_0 t) \exp\left(-\frac{1}{2} t^2 \right) \tag{2}$$

* denotes the complex conjugation of the Morlet wavelet.

The WPS of the continuous wavelet transform is defined as:

$$\mathrm{WPS}_x(\tau, s) = |W_x(\tau, s)|^2 \tag{3}$$

The WPS depicts and measures the local variance of a time series at different time and scales.

3.2 Wavelet coherence

The wavelet coherence technique is a useful tool to analyse the co-movements between two time series in both time scales and frequency bands. The wavelet coherence between two time series is defined as:

$$R_n^2(s) = \frac{\left| S\left(S^{-1} W_n^{XY}(s) \right) \right|^2}{S\left| (S^{-1} |W_n^X(s))|^2 \right| \; S\left| (S^{-1} |W_n^Y(s))|^2 \right|} \tag{4}$$

Where $R_n^2(s)$ indicates the squared wavelet coherence, its value ranges between 0 and 1 and measures the local linear correlation between two time series at a particular scale. S denotes a smoothing operator in both time and scale.

3.3 Partial wavelet coherence

The partial wavelet coherence (PWC) identifies the co-movement between two time series x_1 and x_2 after cancelling the effects of time series x_3. The PWC between x_1 and x_2 after excluding the effect of x_3 can be expressed as follows:

$$RP^2(x_1, x_2, x_3) = \frac{|R(x_1, x_2) - R(x_1, x_3).R(x_1, x_2)^*|^2}{[1 - R(x_1, x_3)]^2[1 - R(x_3, x_2)]^2}$$

where RP indicates the squared partial wavelet coherence, ranging from 0 to 1.

3.4 Phase differences

The wavelet phase difference is introduced to capture positive or negative co-movement and to investigate the lead-lag relationship of two time series.

The phase difference ϕ_{XY} between two time series $X(n)$ and $Y(n)$ is given as (Aguiar-Conraria *et al.*, 2008):

$$\varphi_{X,Y} = \tan^{-1}\left(\frac{I(W_n^{XY})}{R(W_n^{XY})}\right), \tag{5}$$

with $\phi_{XY}\ \epsilon(-\pi, \pi)$

When $\phi_{XY}\ \epsilon(0, \pi)$, the two-time series are in phase and X leads Y, and when $\phi_{XY}\ \epsilon(-\pi/2, 0)$ the series still are in phase but Y is leading. In contrast, the series are out of phase and X leads Y when $\phi_{XY}\ \epsilon(-\pi, \pi/2)$, while Y leads X for $\phi_{XY}\ \epsilon(\pi/2, \pi)$.

3.5 Frequency domain causality test

Breitung and Candelon (2006) developed the frequency domain causality test to provide the causality values between variables at different frequencies, that is causality at different time horizons (short-, medium- and long-term).

The testing procedure by Breitung and Candelon (2006) can be outlined as follows:

Let $Y_t = (x_t, y_t)$ be a covariance stationary vector time series that can be represented by finit order VAR(p) model.

$$Y_t = c_0 + \sum_{j=1}^{p} \alpha_j y_{t-j} + \sum_{j=1}^{p} \beta_j x_{t-j} + \varepsilon_{1t} \tag{7}$$

The null hypothesis of no granger causality from x_t to y_t can be stated as:

$$H_0 : \beta_1 = \beta_2 = \ldots = \beta_p = 0 \tag{8}$$

This test indicates whether the past changes in x_t have an impact on current changes in y_t over a specific period of time.

Geweke (1982, 1984) introduced the concept of linear feedback which provides an alternative to the Granger causality tests. The linear feedback measures statistics were designed to detect a feedback causality and to provide a measure of its strength (Durlauf *et al.*, 1996). Since these tests cannot provide a more detailed explanation of causal influence over different frequencies, Geweke (1982) introduced the frequency domain versions of the linear feedback measures that can provide detailed information about feedback relationship between two variables (or two blocks of variables) over different frequency bands. However, this test turns out to be difficult to implement in practice. Breitung and Candelon (2006) remedy this by reformulating the null hypothesis in terms of two restrictions in the bivariate system.

The null hypothesis of $M_{y\rightarrow x}(\omega) = 0$ is as:

$$H_0 : R(\omega)\beta = 0 \tag{9}$$

$$\text{Where}: \beta = (\beta_1, \ \ldots, \ \beta_p) \text{ and } R(\omega) = \begin{bmatrix} \cos(\omega)\cos(2\omega)\ldots\cos(p\omega) \\ \sin(\omega)\sin(2\omega)\ldots\sin(p\omega) \end{bmatrix} \tag{10}$$

The F statistics of Eqn (10) is distributed as $F(2, \ T-2p)$ for $\omega \in (0, \ \pi)$ where 2 is the degrees of freedom, and T is the number of observations used to estimate the VAR(p) model.

Further, it is important to mention that low frequencies are equivalent to long-run causality and high frequencies represent the short-run causality.

4. Empirical results

4.1 Data description

In this study, we use annual time series data covering the period from 1971 to 2018 to investigate the co-movement and causality between economic growth (GDP per capita constant LCU), energy consumption (kg of oil equivalent per capita) and carbon dioxide emissions (metric tons per capita) in Algeria. The data are sourced from the World Bank's World Development Indicators. The annual growth rates of the selected variables are calculated using the following formula:

$$dx\% = (x_t - x_{t-1})/(x_{t-1})$$

Figure 1 plots the time movements of the selected variables, while Table 1 provides the descriptive statistics. It can be seen that CO_2 emissions experienced the highest degree of volatility owing to maximum standard deviation as compared with economic growth and energy consumption. From Figure 1, we observe that there are important changes in all-time series in 1970s and early 1980s. While, the three variables exhibit less variability since 1990.

However, before carrying on the wavelet approach analysis, we need to investigate the non-linearity of each variable. The BDS test is used to determine non linearity. The BDS test was developed by Brock *et al.* (1996). Brock *et al.* (1996) define the BDS statistics as follows:

$$\text{BDS}_{\varepsilon,m} = \sqrt{N}\,\frac{[C_{\varepsilon,m} - (C_{\varepsilon,1})^m]}{\sqrt{V_{\varepsilon,m}}}$$

$V_{\varepsilon,m}$ is the standard deviation of $\sqrt{N}[C_{\varepsilon,m} - (C_{\varepsilon,1})^m]$

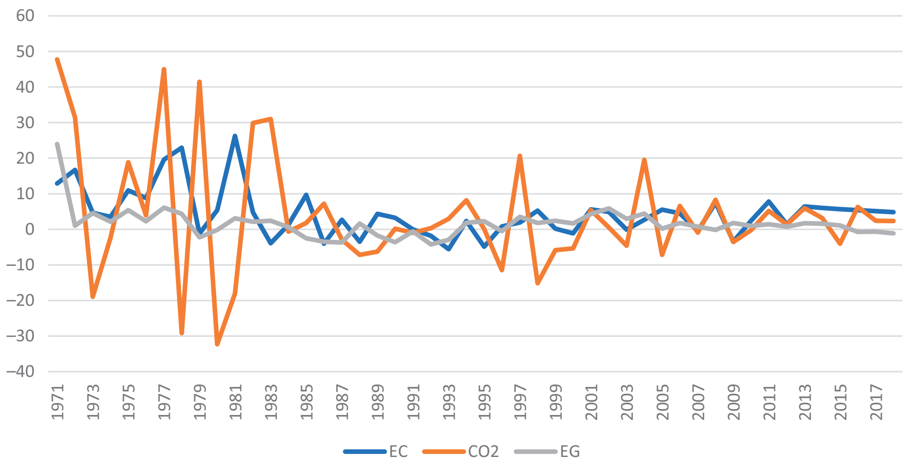

Figure 1.
The growth rates of EG, EC and CO_2

The null hypothesis of the BDS test is that the time series is independent and identically distributed. If the null is accepted, we conclude that there is no non-linear dependence in the residuals. Table 2 depicts the statistic of BDS test for our variables. This table indicates that the calculated BDS statistics for variables (EC, EC and CO_2) are greater than the critical values, thus, we reject the null that the time series are linearly independent. These results suggest that our variables are non-linearly independent, therefore, the necessity of using the wavelet approaches is reasonably justifiable.

4.2 Wavelet power spectrum (WPS) results

To examine the evolution of the variables' power/variance at different time scales the WPS is plotted. Figure 2 shows the WPS of economic growth (EG), energy consumption (EC) and carbon dioxide emissions (CO_2). The horizontal axis indicates the time dimension and the vertical axis depicts the frequency (in years). The colour code indicates the strength of power that range from low power (in blue) to high power (in red). The regions within black lines represent significance level at 5%, within the grey lines at 10%. The white lines show the maxima of the undulations of the wavelet power spectrum, therefore giving us accurate estimate of the cycle period.

	EG	EC	CO_2
Mean	1.549298	4.461109	3.76103
Maximum	23.97503	26.25716	47.74598
Minimum	−4.250994	−5.586464	−32.30965
Standard deviation	4.157148	6.662382	16.61984
Skewness	3.198913	1.311562	0.7383127
Kurtosis	18.81441	5.158313	4.007736

Note(s): EG: Annual change of GDP per capita; EC: Annual change of energy consumption; CO_2: Annual change of carbon dioxide emissions

Table 1. Descriptive statistics

Dimension	BDS statistic	Std. error	*z*-Statistic	Prob
Variable : EG				
2	0.048739	0.011264	4.327083	0.0000
3	0.090304	0.018172	4.969492	0.0000
4	0.108119	0.021969	4.921511	0.0000
5	0.113663	0.023251	4.888616	0.0000
6	0.098939	0.022773	4.344602	0.0000
Variable : EC				
2	0.028453	0.014798	1.922794	0.0500
3	0.050212	0.020773	2.417221	0.0156
4	0.067237	0.021872	3.074094	0.0021
5	0.066157	0.020171	3.279898	0.0010
6	0.057922	0.017220	3.363586	0.0008
Variable : CO_2				
2	0.111813	0.015827	7.064618	0.0000
3	0.200200	0.025581	7.826091	0.0000
4	0.255780	0.030999	8.251122	0.0000
5	0.281984	0.032894	8.572541	0.0000
6	0.303282	0.032307	9.387404	0.0000

Table 2. BDS test for non-linearity

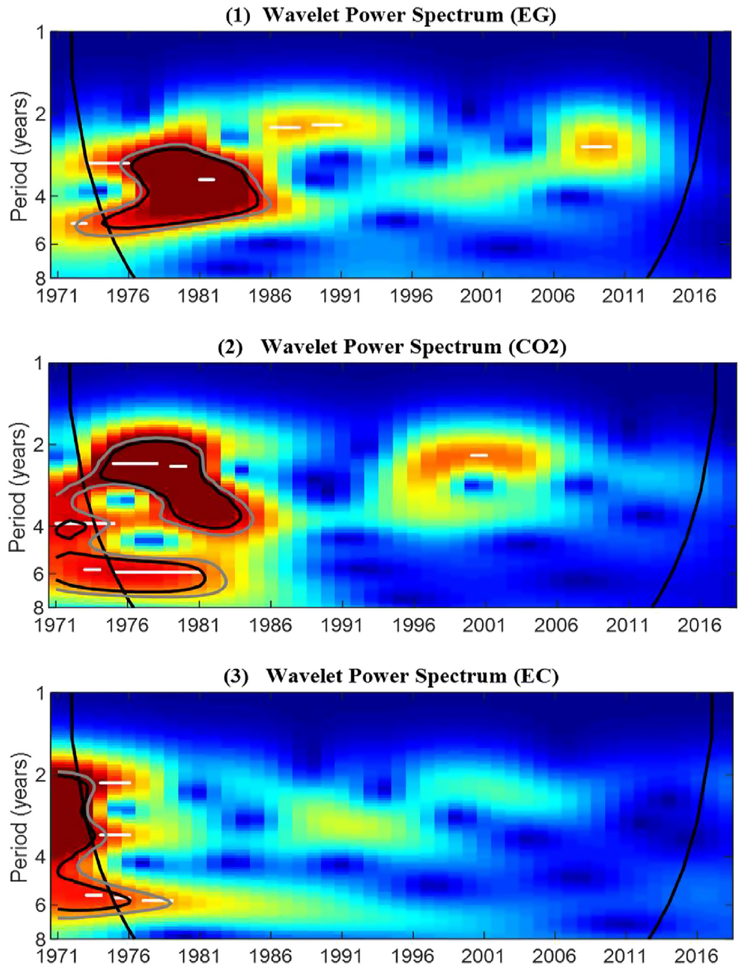

Figure 2.
Wavelet power spectrum (WPS)

Figure 2 clearly shows that EG, EC and CO_2 share so many common significant features in terms of wavelet power. In Figure 2(1) the wavelet power spectrum of EG shows that EG has high and significant fluctuations between 1971 and 1986 at 2–4 years of scale. For CO_2 in Figure 2(2), the wavelet power spectrum shows also significant variations at medium and long frequencies (2–8 years of scale) over the period 1971–1986. In Figure 2(3), EC exhibits high and significant variations at medium frequencies (2–4 years of scale) over the period 1971–1981. The high power in the 2–8 frequency band during 1971–1986 for all variables could be attributed to the industrial strategy developed in the 1960s and 1970s, where the Algerian government invested billions of petrodollars to develop the manufacturing sector. The industrialization drive of the 1970s increased hydrocarbons production and consumption leading to more carbon emissions. In addition, we observe a white line on periods 3, 4 and 6 for CO_2 over the period 1971–1981, a white line on periods 2, 4 and 6 for EC over the period 1971–1981 and white line on periods 2, 3, 4 and 5 for EG over the period 1971–1986, meaning that these periods have a permanent cycle. A comparison of the power spectrum of the time series reveals that there are similarities in the relevant periodicities of EG, EC and CO_2.

4.3 Wavelet coherence results

In addition, the wavelet coherence is used to analyse the associations between the selected variables. Figures 3–5 plot wavelet coherency and phase differences of EG-CO_2, EC-CO_2 and EG-EC, respectively. Figure 4 reveals some areas of strong coherency between EG and CO_2 emissions. Co-movements are observed between EG and CO_2 emissions at 1–4 and 4–8-years frequency during 1971–1985, and 1994–2011 at 1–2 years frequency. The phase difference lies in $[0, \pi/2]$ indicates that during 1971–1985 (at 1.5-4- and 6-8-years frequency) the two variables are in-phase (i.e. moving in the same direction), with EG as the leading variable. Similarly, we can observe a short-term relationship between EG and CO_2 emissions during 1994–2011 at 1–2 years frequency. Over the period 1994–2006, the phase difference $[0, \pi/2]$ suggests that they are positively correlated, with EG leading. While during 2006–2011, phase difference $[-\pi/2, 0]$ demonstrates a positive correlation between EG and CO_2 emissions, with CO_2 leading.

Figure 4 shows the wavelet coherence between EC and CO_2 emissions. In the 1–4 years frequency band, the variables are in phase for the whole sample period, excepting the sub period 1986–1991 where the relationship changes to out phase one. However, at 4–8 years

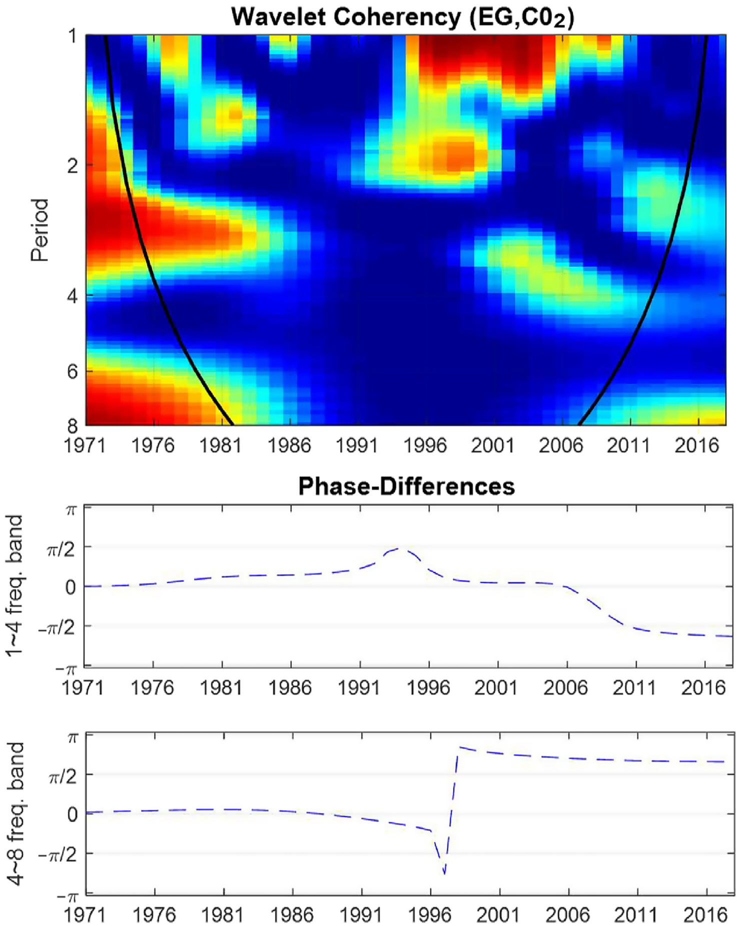

Figure 3.
Wavelet coherence between EG and CO_2

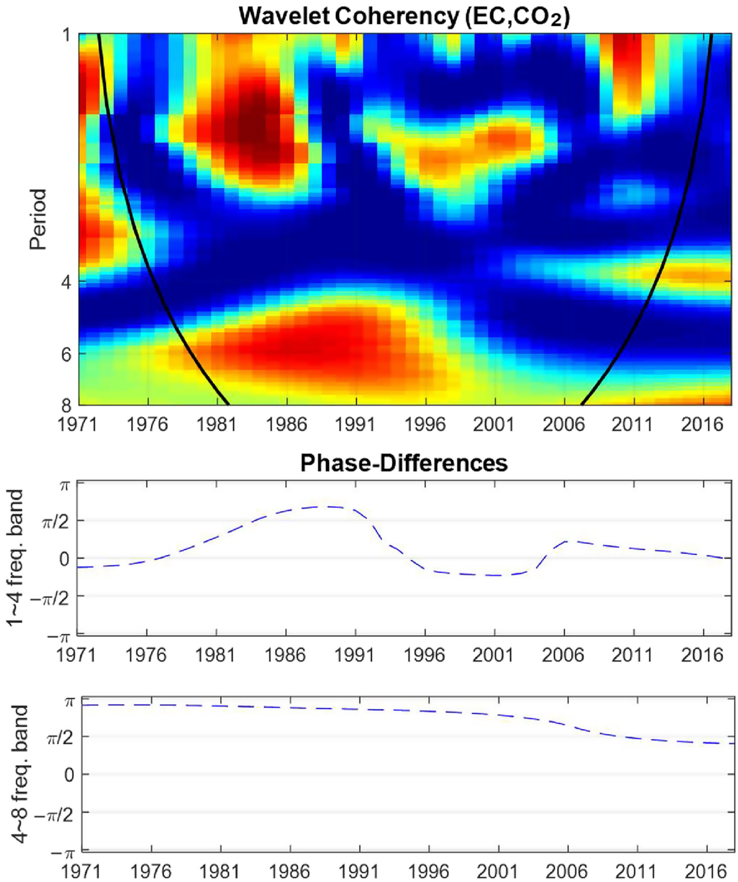

Figure 4.
Wavelet coherence between EC and CO_2

frequency band the pair EC and CO_2 emissions are out phase for the period 1976–1998 and in phase during the period 2006–2018.

Results of wavelet coherence between EG and EC are provided in Figure 5. The wavelet coherence of EG-EC reveals a co-movement during the periods 1971–1977 at 2–4 years frequency, 1977–1983 at 1–2 years frequency, 1991–2005 at 1.5–4 years frequency and 2006–2018 at 4–8 years frequency. Over the period 1971–1983, the variables are in-phase. During 1971–1977 at 2–4 years frequency, as phase difference lies in $[0, \pi/2]$, EG positively leads EC, while at 1–2 years frequency, the phase difference $[-\pi/2, 0]$ implies that EC positively drives EG during 1977–1983. Over the period 1991–2005 at 1–2 years frequency EG leads EC, the phase difference lies in $[0, \pi/2]$. In this case, the variables are still in-phase. In the long run (4–8 years frequency) between 2006 and 2018, the phase difference lies in $[0, \pi/2]$, this means that EG and EC are in-phase, with EG as the leading variable.

In sum, the wavelet coherence results in Figures 3 and 4 indicate that there are significant co-movement periods between EG-CO_2 and EC-CO_2 in Algeria across different frequencies. We can observe also a weak co-movement between EG and EC. Moreover, the lead-lag relationships between EG, EC and CO_2 emissions reveal that EG and EC tend to lead CO_2 emissions across almost the whole sample period.

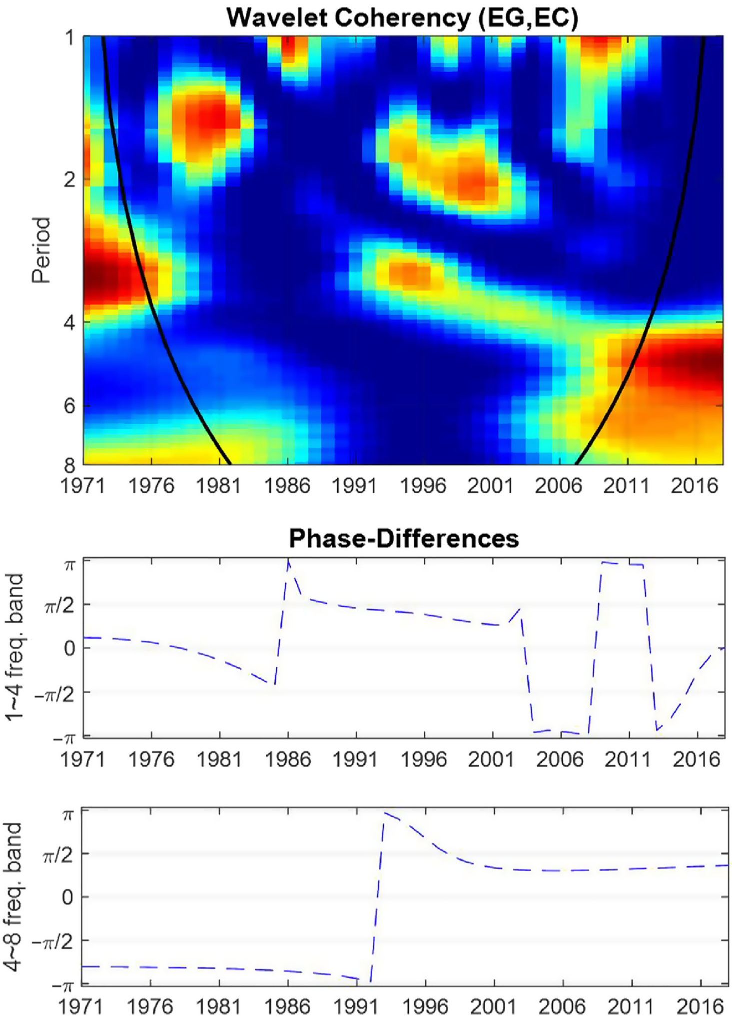

Figure 5.
Wavelet coherence between EG and EC

4.4 Partial wavelet coherence results

In this sub-section, the results of PWC among EG, CO_2 emissions after concealing out EC are presented in Figure 6. When considering EC in the relationship between EG and CO_2 emissions (Figure 5), we observe strong co-movement for all frequency bands during the whole sample period. In the short run, we identify two significant and large areas of strong co-movement among EG and CO_2 emissions during the periods 1994–2008 at the 1–2 years frequency and 1971–1990 at 1.5–4 years frequency. Partial phase difference lies in $[0, \pi/2]$ shows an in-phase partial coherence between EG and CO_2, running from EG to CO_2 emissions during these two sub-periods. Two other small significant areas are identified for the 1–2 years frequency (i.e. a short-term horizon) during the sub-periods 1978–1982 and 1984–1987, where the variables are positively correlated and EG is leading CO_2 emissions. In the medium- and long-term EG and CO_2 emissions are positively correlated during 1971–1975 and 1990–2014 at 4–8 years frequency. Over the former period, the phase difference zero indicates that

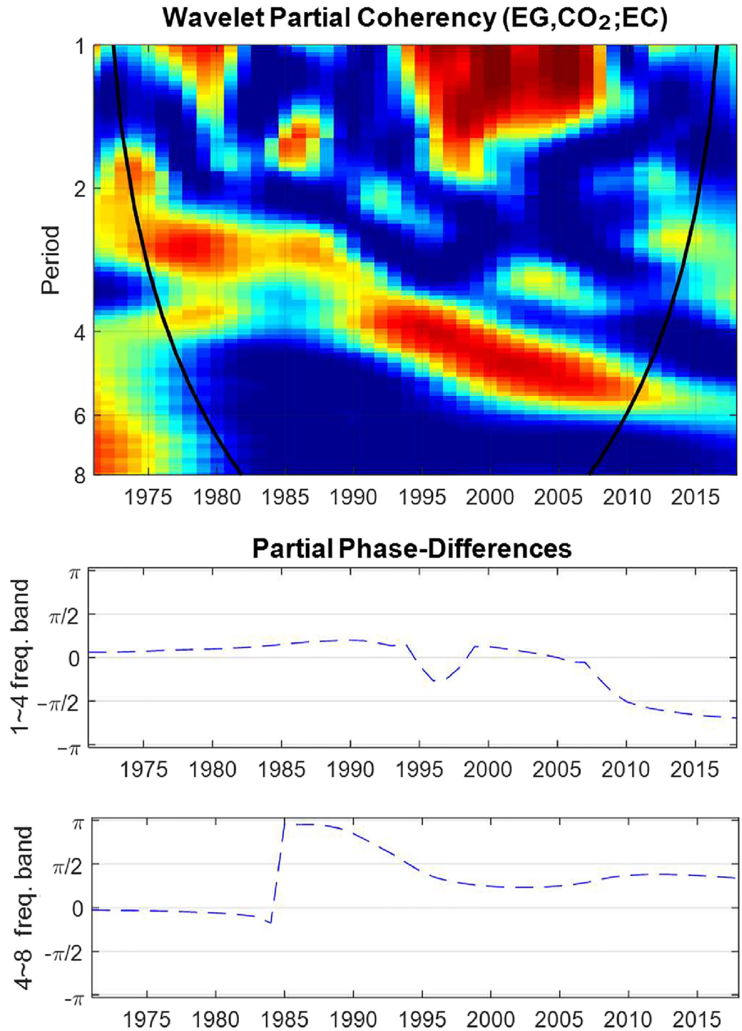

Figure 6.
Partial wavelet coherence (EG, CO_2; EC)

they are positively linked and move together, while during the later period, phase difference $[0, \pi/2]$ suggests an in-phase coherence between EG and CO_2 emissions, and CO_2 lags EG.

In summary, the partial and wavelet coherence results indicate a strong effect of EG (economic growth) on both CO_2 emissions and EC (energy consumption) in Algeria. This implies that an increase in economic growth is leading to more environmental degradation caused by CO_2 emissions.

This finding may be linked to the fact that Algeria is an oil dependent country, where its economy is highly dependent on oil and gas exports, which are more than 95% of total exports and provide almost 60% of budget revenues and over a third of GDP.

4.5 Frequency-domain causality test

For robustness analysis, we perform the Breitung-Candelon (2006) frequency domain spectral causality test to identify causal links among variables. Figure 7 displays the outcome of this test for all frequencies $\omega \in (0, \pi)$ with the 5% critical value. The first plot in Figure 7a shows the EG granger causes CO_2 emissions for frequencies above 0.66 corresponding to wavelengths longer than 9.5 years. Similarly, Figure 7b indicates that EC granger causes CO_2 emissions for frequencies below 1.72 corresponding to cycle larger than 3.6 years. These frequency domain results suggest that EG and EC impact CO_2 emissions both in short and long run. Furthermore, these results appear in line with the findings of wavelet coherence and partial wavelet coherency regarding the existence of a strong significant impact of both EG and EC on CO_2 emissions. This finding is not surprising, given that Algeria is an oil exporting country, and its economy is highly dependent on revenues from oil and gas exports, which increases CO_2 emissions. In addition, energy price subsidy is another factor that drives up energy consumption, which in turn leads to more carbon emission.

Figures 7c and 7d present the results of frequency domain for causality between EG and EC. Figure 7c shows that at 10% level of significance EG granger causes EC for frequencies below 0.58 (cycle larger than 10 years) reflecting long-term cycles. Figure 7d reveals that at 10% significance level, EC granger causes EG for frequencies between 1.59 and 2.7, reflecting medium-terms cycles (i.e. between 3.94 and 2.33 years). These results reflect weak causal relationship between EG and EC and confirm the results of wavelet coherence, suggesting weak co-movement between the two variables.

5. Conclusion

The objective of our study is to examine the association between economic growth, energy consumption and CO_2 emissions in Algeria, based on the wavelet approach and spectral granger causality technique over the period 1971–2018. The results of WPS indicate that the selected variables share common strong variance in the medium and long run. In the case of EG and CO_2 emissions, the WPS exhibits many regions of high power at 2–6 years scale during the early 1970s, late 1980s and post 2000. Likewise, in the case of EC a strong variance in the medium and long run is observed during 1970s. The lead lag relationship between the variables is analysis by estimating the wavelet coherence. The results show that there is a significant co-movement between EG and CO_2 emissions in all time scales, with EG as the leading variable. Some weak co-movement is also found between EG and EC. Furthermore, the results of partial wavelet coherence indicate that there is a significant positive relationship between EG and CO_2 emissions, and EG is the leading variable for CO_2 emissions and EC. This means that the economic growth increases the global carbon emission via energy consumption. For robustness analysis, spectral causality analysis was performed and the results of this spectral causality test suggest that both EG and EC cause CO_2 emissions both in short and long run. The results also reveal a weak bidirectional causality between EG and EC. The causalities between economic growth and carbon emissions and energy consumption and

It has been established by this study that economic growth and fossil fuel consumption contribute towards higher level of carbon dioxide emissions in Algeria. The findings have important policy implications. Algeria is one of the oil-rich countries and it is strongly reliant on fossil fuel energy. While the country is also the richest in renewable energy. Therefore, Algerian authorities should promote renewable energy production and shift gradually towards reducing non-renewable energy consumption, owing to its negative impact on environmental quality through increasing carbon emissions. Algeria has enormous renewable energy resources such as solar, wind, biomass and geothermal energy, while the share of energy from renewable resources in Algeria is very low compared to the available potential. Therefore, Algeria is in urgent need to integrate renewable resources into its energy strategy, particularly solar energy. Algeria has the most important solar energy potential of the Mediterranean basin, with about 170000 TWh per year.

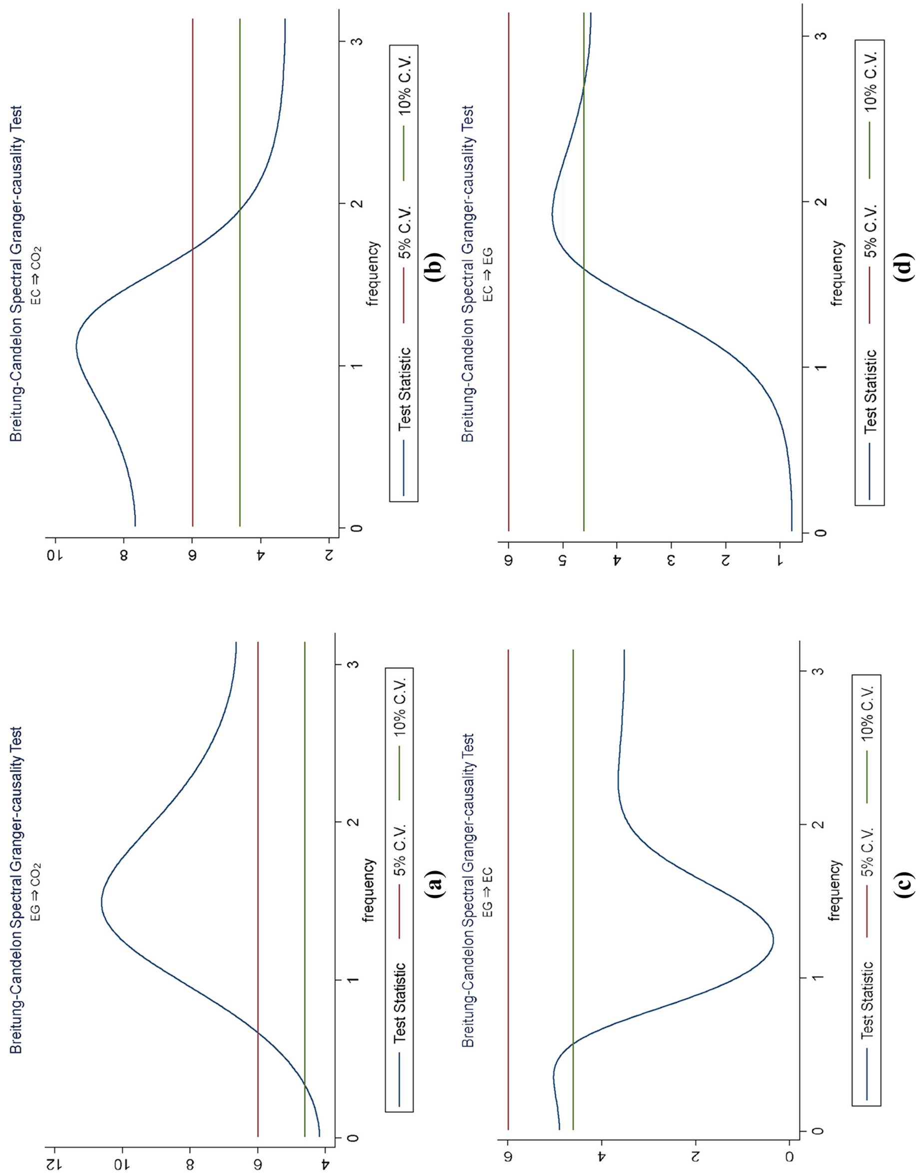

Figure 7.
Breitung-Candelon spectral Granger causality test

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