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Research article

Revisiting the Energy-Growth nexus with debt channel. A wavelet time-frequency analysis for a panel of Eurozone-OECD countries

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Abstract: In this paper, continuous wavelet decompositions regarding the notions of coherence and phase are used to analyze the time-frequency dynamics of the existing relationships between energy supply and economic growth for a group of European countries. The objective is to identify both the intensity and the direction of the relationship over time and across frequencies. We also study the existence of a debt channel implying an indirect relationship between energy and growth. Our results show the complexity of the energy supply-growth relationship composed by direct effect at the short run and indirect effects through debt channel at the mid and long run. The countries with the highest debt/GDP ratio are more subject to such direct and indirect effects than others where only short run direct effect is noted.

Keywords: wavelet analysis; OECD European countries; energy supply; public debt; economic growth

JEL Codes: C22, C30, F43, H63, Q41

Abbreviations: OECD: Organization for Economic Co-operation and Development; IEA: International Energy Agency; GDP: gross domestic product; CWT: Continuous Wavelet Transform

1. Introduction

In the current context of post-Covid-19, the energy shock and economic crisis due to the Russo-Ukrainian conflict highlight the role played by energy supply as an essential factor for economic development and public debt. Energy is also a key variable both on the supply-side and demand-side, because many energetic commodities are purchased by the consumer while being an important production factor for every product. For many countries, energy supply is a vital good for their domestic consumption and industrial production, affecting both welfare and living standards. Consequently, the researcher's attention focuses on the relationships between energy and economic growth to include energy in the policy toolbox.

Regarding the relationship between energy and growth, we can identify two main points of view. First, part of the literature suggests that energy consumption can limit growth with a varying impact with countries' structure and economics cycles. In particular, the GDP share of energy-intensive sectors of activity (industry, etc.) constitutes a structural factor, as emphasized in the works of Cheng (1995), Asafu-Adjaye (2000), and Solow (2016). Then, reduction or limitations in energy supply can negatively affect economic growth, increasing transportations and production costs and generating an adverse effect on social welfare, as indicated by Halldorsson and Svanberg (2013). Second, many studies have pointed out that energy can have a positive effect on growth, assuming that increased energy consumption is due to increased growth. From this, energy is a key determinant of productivity, industrial output, and ultimately an essential input for the modern economy.

It is therefore common to define several hypotheses on the direction and intensity of the relationship between energy and growth and then on the relevance of energy policy as outlined in an extensive literature (Jumbe, 2004; Shiu and Lam, 2004; Altinay and Erdal, 2005; Chen et al., 2007; Mozmuder and Achla, 2007; Squalli, 2007; Apergis and Payne, 2010; Oztruk and Acaravci, 2010). The growth hypothesis implies a unidirectional relationship and a major role for energy, both direct and indirect, which is a factor of production. In this context, a restrictive (respectively conservative) energy policy will negatively (resp. positively) affect growth and output (Yu and Choi, 1985; Tsani, 2010; Belke, 2011; Destek, 2016). In contrast, the conservation hypothesis assumes an inverse relationship, making economic growth the main driver of energy consumption. Any policy on energy consumption will have little effect on growth. Therefore, a restrictive policy will have little or no negative effect on growth (ShyamaL and Bhattacharya, 2004; Hatemi and Manuchehr, 2005; Gelo, 2009). The neutrality hypothesis is quite close to the previous one by assuming that there is no relationship between energy and growth. Therefore, all energy policies do not affect the growth, neither positively nor negatively (Jobert and Karanfil, 2007). The feedback hypothesis implies a bidirectional relationship, implying that an energy policy must be complemented by economic measures to either attenuate or remove its negative effects on growth or production (Hondroyiannis, 2004; Lee et al., 2008; Mutascu, 2016; Dos Santos et al., 2017). Numerous studies and works focused on several countries either confirm or refute these different hypotheses. Akinlo (2008) and Sakiru Adebola (2011) show that there is a casual unidirectional relationship from consumption to growth for a panel of African countries, while an inverse causal relationship is noted for the US by Abaidoo (2011). Behname (2012) found a bidirectional causality. Using cointegration approaches on European data, Erol and Yu (1987) found mixed and different results across countries. For example, there is no relationship for France, UK, and Canada, but found a bidirectional causality for Italy. On a panel of Asian countries, Masih and Masih

(1996) confirmed mixed results, which varied according to the country. Chontanawat et al., (2008) studied the energy-growth relationship for a large panel of 100 OECD and non-OECD countries. Their conclusions show that, for OECD countries, the relationship is unidirectional and that consumption affects growth; meanwhile, for non-OECD countries, this hypothesis is observed for 46% of the sample.

Giraud and Kahraman (2014) and Carminel (2015) assume that the supply of raw materials and primary energy products may limit the intensity of the energy consumption-growth relationship for countries dependent on the import of fossil fuels. Their results are consistent with European countries that imported more than half of their energy consumed for approximately 1 billion euros per day. The previous work highlights the crucial effect of the energy supply on economic growth, assuming a relationship between energy supply and public debt. Gomez-Puig et al., (2015) emphasized that for some OECD European countries, the pace of growth is conditioned by either energy supply or by their debt policies for others. Algieri (2014) also indicated the necessity to better understand the relationships between growth, debt, and energy supply to fit policy recommendations with countries' economics situations. Consequently, energy consumption appears to be dependent on the abilities of the country to ensure and secure their energy supply. Then, in the current context, the energy supply-debt relation emerges for European countries, mainly dependent on energy imports to satisfy their needs.

In parallel, the relationship between public debt and economic growth has been the topic of several studies since the 2008 global financial crisis and the related European debt crisis of 2011–2012. For countries with a high debt ratio, several studies focus on the effect of debt level on growth. Notably, Ferreira (2009) and Puente-Ajovin (2015) point to the reverse causal effect from growth to debt. Bell et al., (2015) found that public debt is likely to accumulate in periods of low growth. In this respect, as government revenues are more limited, governments are nevertheless forced to increase their debt levels to maintain a certain level of general welfare, fostering short-term demand to boost long-term growth (Feldstein, 2014). The neoclassical model of endogenous growth (Modigliani, 1961; Diamond, 1965; Saint-Paul, 1992; Aizenman et al., 2007) implies that a high debt ratio reduces the long-term growth rate. This negative effect can be partly explained by the overhang, crowding out, or uncertainty (Krugman, 1988; Roubini and Sachs, 1989; Codogno et al., 2003; Hansen, 2004; Cochrane, 2011) hypotheses. Another factor that can explain these results is the rate (Elmendorf and Mankiw, 1999; Tanzi and Chalk, 2000) or the process of liberalization of the financial sector, which makes different countries interconnected (Eichengreen and Leblang, 2003; Nyambuu and Lucas, 2015). Checherita-Westphal et al., (2012) Panizza and Presbitero (2014) Mencinger et al., (2014) show that for European countries, the effect of debt on growth is non-linear and negative with a threshold on the debt ratio of 90%/100%.

Nowadays, energy remains an essential resource for industrial and economic development. However, the production and consumption of energy requires significant investment, which often leads to high levels of debt. The more indebted an economy is, the less capital is available to invest in other sectors of the economy, which can hinder economic growth. On the other hand, economic growth can also lead to increased debt as governments borrow money to finance new projects and opportunities. Thus, the relationship between energy, debt, and economic growth is complex and intertwined (Sadiq et al., 2022; Jamil, 2022; Efthimiadis et al., 2023).

Revisiting the direct effects of the energy-growth relationship while considering the indirect effect throughout debt channel appears to be an important issue, especially in a context of high indebtedness of developed OECD European countries. The weight of energy supply in the debt could severely affect growth. This paper aims to revisit the cross-relationships between energy supply, public debt, and economic growth for a panel of OECD European countries, while considering the term of several economic cycles. As underlined in the literature, the question of the term is decisive, because the different causal hypotheses are conditional to a horizon (short, medium, or long term).

To study the relationships between our variable according to different cycles frequencies (periods), we use a time-frequency wavelet-based approach suitable for these types of objectives, as shown in the economic and financial literature (Aguiar-Conraria and Soares, 2008; Aguiar-Conraria et al., 2011; Bekiros et al., 2016; Oral and Unal, 2017; Gulerce and Unal, 2018; Mestre, 2021; Mestre, 2023; and Uddin et al., 2021). In this framework, the notion of frequency illustrates the amplitude of the different cycles of a time series. Thus, low frequencies correspond to long-term cycles and high frequencies correspond to short-term cycles. For our study, one of the main interests of this approach is the wavelet coherence, which allows us to calculate the intensity of the co-movements between the different cycles of the two variables (i.e., the degree of synchronization). Thus, this concept is close to the definition of the standard notion of correlation/determination, with the advantage to describe their time dynamics and frequency differentiation. Other advantages of using wavelets are the time-frequency varying phase differences between two cycles. This concept indicates, at the same frequency, if two cycles are either in phase or anti-phase, then the two variables are either positively or negatively correlated, respectively. The value of the phase difference also confirms whether the cycles of one variable predetermine those of another. In this case, a variable is identified as the leader/driver of the relationship (Mestre and Terraza, 2018). Note that both coherence and phase are frequency-varying but also time-varying. Finally, we can analyze complex interactions between energy supply, debt, and growth overtime and for various economic cycles in a dynamic framework.

Our results show the complexity of the energy supply-growth relationship composed by direct effect at the short run and indirect effects through the debt channel at the mid and long run. However, the countries with the highest debt/GDP ratio are more subject to such direct and indirect effects. In this case, the energy supply appears to be a determining factor that could strongly amplificated their debt level.

This paper is organized as follows. First, we present first the methodology and the data used. In a second part, we proceed with the wavelet approach to analyze the obtained results.

2. Data and methodology

2.1. Data description

In this paper, we have conducted an analysis of nine OECD European countries for which the most energetic and macroeconomic annual data are available from 1970 to 2017. The list includes Germany, Belgium, France, and the Netherlands as the core of Europe, major peripherical countries (Ireland, Italy, Greece, and Spain), and Finland as a Scandinavian eurozone member. In addition, these countries can be distinguished by their indebtment level and macroeconomics characteristics, as described in Benassy-Quere (2017). Germany and the Netherlands have a lack of public investment and excessive private indebtment level with a high competitivity, while France and Italy have a high public indebtment level with unemployment and low competitivity. Greece is characterized by a deteriorated economic situation following the European debt crisis of 2011–2012.

The data was obtained from the OECD Economic Outlook No 105-May 2019 (primary energy supply, general government gross financial liabilities, and gross domestic product volume market prices). To complete the series, we have also used the OECD Economic Outlook No 73-June 2003 for all the countries selected to have the largest observations possible (data calibration between two data sources).

We consider the annual variation of the primary energy supply (ESU), the public debt (PDE), and the economic growth (EGR) of each of the countries of interest. According to the OECD, the primary energy supply is defined as the energy production plus energy imports, minus energy exports, minus international bunkers, then either plus or minus stock changes. The IEA energy balance methodology is based on the calorific content of the energy commodities and a common unit of the account is the tone of oil equivalent (toe). Toe is defined as 107 kilocalories (41.868 gigajoules). This quantity of energy is, within a few percent, equal to the net heat content of one tone of crude oil. The difference between the "net" and the "gross" calorific value for each fuel is the latent heat of vaporization of the water produced during the combustion of the fuel. For coal and oil, the net calorific value is about 5% less than the gross, for most forms of natural and manufactured gas the difference is 9–10%, while for electricity, the concept of calorific has no meaning. The IEA calculates balances using the physical energy content method to find the primary energy equivalent. This indicator is measured in million toes and toe per 1,000 USD. Second, public debt refers to the total financial commitments made in the form of loans by the State, public authorities, and the organizations that depend directly on them. It is constantly changing as a function of the rate of repayment of loans by the State and public administrations and the new loans they take out to finance their deficits, which occurs when expenditure, made possible by borrowing, exceeds revenue, leading to an increase in debt. Finally, a country's growth is measured by the increase in its gross domestic product over a given period: either month, quarter, half-year, or year. It is calculated in "constant euros" (i.e., excluding price increases). It is manifested by a significant and lasting increase in the supply of goods and services. This positive fluctuation is evaluated by the annual variation of GDP indicator, evaluated in constant currency to take account of inflation. This is an indispensable, but not always sufficient, modality for development. Therefore, gaining a greater understanding of the interactions between these variables is immensely useful for policy formulation.

2.2. Wavelets approaches technical considerations

Time-frequency analysis by continuous wavelets represents an improvement of the Fourier approach by allowing a temporal representation of the frequency components of a chronicle. Meyer et al (1986), and Grossmann and Morlet (1984) are considered the fathers of wavelet theory, but they have been popularized by Mallat (1989; 2000; 2009) and Daubechies (1992) in signal processing. In the rest of this presentation, the formulas and notations are based on the previously mentioned works of Mallat (1989; 2000; 2009) and Mestre (2019; 2023).

A Continuous Wavelet Transform (CWT) is based on the master wavelet denoted $\psi(t)$, which is transliterated by τ and dilated by s to extract information from a chronicle $x(t)$ over several frequencies. The set of translated-dilated versions of $\psi_{\tau,s}(t)$ constitutes the following wavelet family, with $\psi^*\left(\frac{t-\tau}{s}\right)$ the conjugate complex of $\psi_{\tau,s}(t)$:

$$\psi_{\tau,s}(t) = \frac{1}{\sqrt{s}}\psi\left(\frac{t-\tau}{s}\right)$$

The CWT consists of projecting $x(t)$onto the family $\psi_{\tau,s}(t)$ to obtain the variations of the chronicle in an area in the vicinity of $t \mp \tau$ and frequency width s. By varying τ and s, we obtain the following wavelet coefficients $W(s,\tau)$ in this way:

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

A reconstruction of the series is done by the following inverse operation:

$$x(t) = \frac{1}{C_{\psi}}\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} \psi_{\tau,s}(\mathrm{t})\, W(s,\tau)\frac{\mathrm{d\tau ds}}{\mathrm{s}^2}$$

This expression brings out the C_{ψ} existence condition of wavelets, with f the frequency and $\widehat{\Psi}(f)$ the Fourier transform of the mother wavelet:

$$C_{\psi} = \int_{0}^{+\infty}\frac{|\widehat{\Psi}(f)|^2}{f}df < +\infty$$

This condition is satisfied if $\psi(t)$ has zero mean and allows variance preservation during decomposition:

$$\int_{-\infty}^{+\infty}\psi(t)\,dt = 0 \quad \text{et} \int_{-\infty}^{+\infty}|\psi(t)|^2\,dt = 1$$

There are several families of mother wavelets with different characteristics, like orthogonality, symmetry, and compactness of its support, as shown by Farge (1992) and by Daubechies (1992). In this paper, we retain the Morlet complex continuous wavelet $\psi_M(t)$, which is characterized by a balance between the temporal and frequency localization,

$$\psi_M(t) = \pi^{-1/4}e^{if_0t}e^{(-\frac{t^2}{2})}$$

with $i^2 = -1$ and f_0, the non-dimensional frequency, which in our case is equal to 6 in order to satisfy the eligibility condition, as shown by Torrence and Compo (1998).

Frequency sampling is performed for practical implementation because of computational power limitations very quickly. Practical obstacles to the use of CWT led Lau and Weng (1995) and then Torrence and Compo (1998) to define the set of scales s_j of a maximum order CWT decomposition J, possessing both good resolution and reasonable computation times. These formulas are defined from the size of the series N (and thus δ_t the time step) and the frequency step δ_j, with δ_j the frequency step, δ_t the time step, and $s_0 = 2\delta_t$ is the smallest computable scale (equal to 2 years in our case):

$$s_j = s_0.2^{j\delta_j}$$
$$\forall\ j = 0, \dots .J$$

$$J = \frac{1}{\delta_j}\left\lfloor Log_2(\frac{N\delta_t}{s_0})\right\rfloor = \frac{1}{\delta_j}\left\lfloor Log_2(\frac{N}{2})\right\rfloor$$

The degree of resolution of the CWT is therefore defined by δ_j, which allows one to consider $(\frac{1}{\delta_j} - 1)$ intermediate scales between two dyadic scales (by multiple of 2). The lower δ_j is valued, the higher the number of intermediate scales is valued, and therefore, the finer the frequency mesh s_j is valued, but its implementation is complex. The choice of δ_j is also related to the master wavelet, and in our case, its value should not exceed 0.5. We set the value of δ_j to 1/8 in order to obtain a large frequency mesh and a reasonable calculation time.

The interpretation of the frequency scales s_j can be facilitated by expressing them in a Fourier period, whose unit is similar to the initial chronicle. Meyers et al (1993) propose a conversion factor F_c specific to the Morlet wavelet selected:

$$T_j = s_j * \frac{4\pi}{f_0 + \sqrt{2 + f^2{}_0}}$$

$$F_c = \frac{4\pi}{f_0 + \sqrt{2 + f^2{}_0}} = 1.033$$

Applied to our data, the frequency grid allows one to study co-movements between paired variables according to various economics cycles. Then, the frequency units indicate the period of the corresponding cycle: short-run cycles with periods of 2 to 4 years, medium periods of 4 to 6 years, and long-run cycles with periods longer than 6 years.

In a multivariate framework, the CWT allows us to redefine certain statistical notions such as the correlation in the time-frequency space. For this purpose, the notions of Coherence and Wavelet phases are similar in interpretation to the correlation-determination (i.e., R^2) as indicated by Grinsted et al (2004), but their particularities lie in their capacity to transcribe statistical information in time (time dynamics) and according to different frequencies (frequency dynamics).

Considering two times functions $x(t)$and $y(t)$ of similar size N, we can obtain their respective wavelet coefficients $W_x(s,\tau)$ and $W_y(s,\tau)$ via CWT, respectively. The time-frequency covariance is obtained by crossing the wavelet coefficients. $SW_{xy}(s,\tau)$ represents the cross-transformation, $W_x(s,\tau)$ refers to the wavelet coefficients from the transformation, and $W_y^*(s,\tau)$ refers to the conjugate complex of $W_y(s,\tau)$.

$$SW_{xy}(s,\tau) = W_x(s,\tau)W_y^*(s,\tau)$$

The wavelet coherence, denoted $WQ(s,\tau)$, between the two functions is obtained by dividing the cross-wavelet spectrum by the power spectra of each function[1] (with G(.) representing the time-frequency smoothing):

$$WQ(s,\tau) = \frac{\left|G(s^{-1}.SW_{xy}(s,\tau))\right|^2}{G(s^{-1}.|W_x(s,\tau)|^2).G(s^{-1}.\left|W_y(s,\tau)\right|^2)}$$

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[1] We use the Package-R Biwavelets of Gouthier, Grinsted and Simko based on the programs of Torrence and Compo (1999).

We observe the similarity of the coherence with the coefficient of determination, for each frequency scale s_j, defined by δ_j, and each instant of time, we obtain a value between 0 and 1. However, in our case, they are complex due to the use of the Morlet wavelet. In its real representation, the coherence is therefore equal to 1 regardless off τ making any interpretation useless. The use of a temporal-frequency smoothing, noted G(.), is necessary to obtain interpretable values in practice. A smoothing of the frequency scales for a given time t, noted as $G_{scale}(.)$, takes place first, followed by the smoothing in time $G_{time}(.)$ for a fixed scale s. The general smoothing operator G(.) is written as follows:

$$G(W(s,\tau)\,) = G_{scale}(G_{time}(W(s,\tau)))$$

The mathematical expressions for $G_{time}(.)$ and $G_{scale}(.)$ are given by Torrence and Webster (1999), with c_1 and c_2 as the normalization constants and $\Pi\,(.)$ as the rectangle or indicator function that takes the value 1 in an interval [−0.5; 0.5] and 0 otherwise, where is:

$$G_{time}(.) = W(s,\tau)c_1^{\frac{-t^2}{2s^2}}$$

$$G_{scale}(.) = W(s,\tau).\,c_2\Pi(\,0.6\,s)$$

The difference of phase between two chronicles is a complementary value allowing one to obtain the sign of the relation, as well as the mutual influences between the variables (with the notion of "Leader"). The wavelet phase function, denoted $\theta_{x,y}(s,\tau)$, is defined as the quotient between the imaginary $\Im$ and real $\Re$ part of $SW_{xy}(s,\tau)$.

$$\theta_{x,y}(s,\tau) = arctan(\frac{\Im(SW_{xy}(s,\tau))}{\Re(SW_{xy}(s,\tau))})$$

The study of the values of the phase, included between [−π, π], allows the analysis of the sign of the relations and the mutual influences between the two variables by determining the "Leader".

3. Results and discussions

In this part, the intensity of the wavelet coherence is visualized with the following color code: the more the color tends towards warm red, the stronger the coherence between $x(t)$ and $y(t)$; conversely, the more the color tends to dark blue, the weaker the coherence between $x(t)$ and $y(t)$. The x-axis represents the time, while the y-axis is for the frequencies of the various cycles. The high-frequencies (short-run) are located at the top and the low-frequencies (long run cycles) are located at the bottom.

For the phase, the orientation of the arrows on the graph allows to distinguish the following cases:

- The arrows point to the top right when $\theta_{x,y}(s,\tau)$ belongs to the interval $\left[0,\frac{\pi}{2}\right]$. The series are in phase and positively correlated, and in this case, $x(t)$ is the leader.
- The arrows point to the top left when $\theta_{x,y}(s,\tau)$ belongs to the interval $\left[\frac{\pi}{2},\pi\right]$. The series are out-of-phase and are therefore negatively correlated, and in this case, $y(t)$ is the leader.
- The arrows point down right when $\theta_{x,y}(s,\tau)$ belongs to the interval $\left[-\frac{\pi}{2},0\right]$. The series are in phase and positively correlated, and in this case, $y(t)$ is the leader.

- The arrows point to the bottom left $\theta_{x,y}(s,\tau)$belongs to the interval $\left[-\pi,-\frac{\pi}{2}\right]$. The series are out-of-phase and are therefore negatively correlated, and in this case, $x(t)$ is the leader.

In Figure 1, graph 1 describes the relationship between energy supply (x) and public debt (y). Graph 2 describes the relationship between energy supply (x) and economic growth (y). Graph 3 describes the relationship between public debt (x) and economic growth (y).

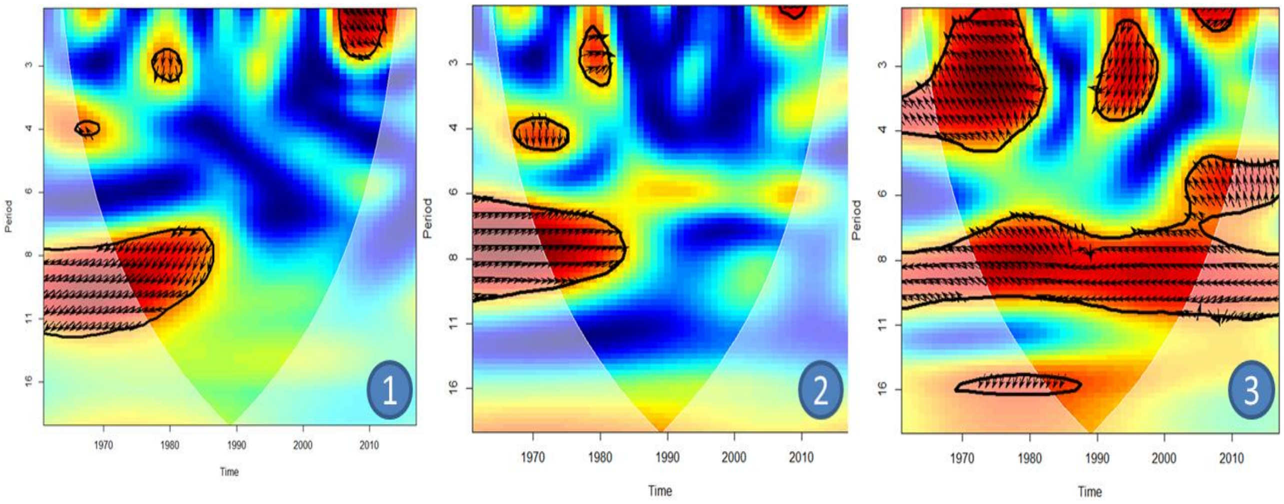

Figure 1.1. Germany.

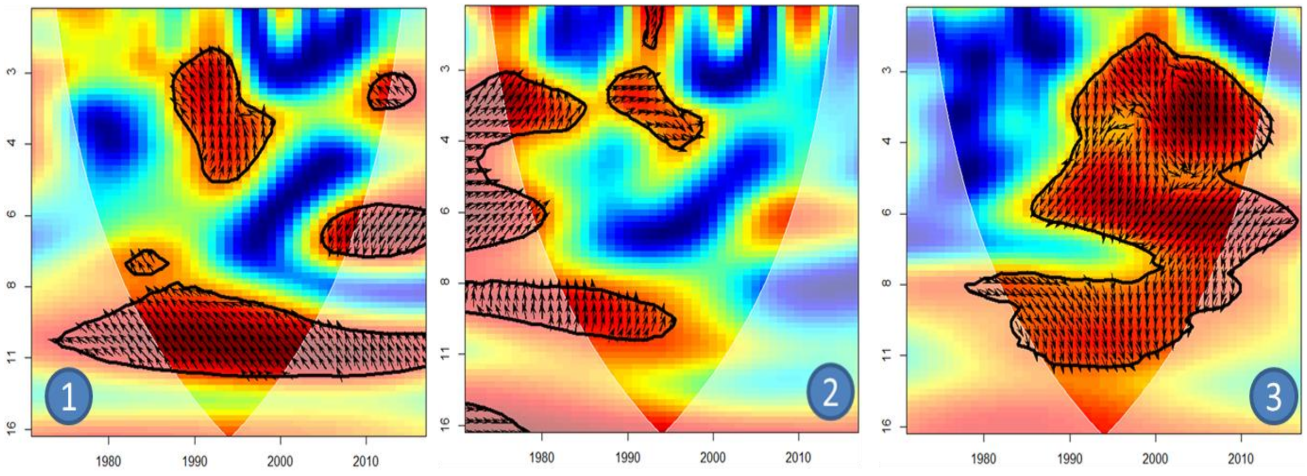

Figure 1.2. Belgium.

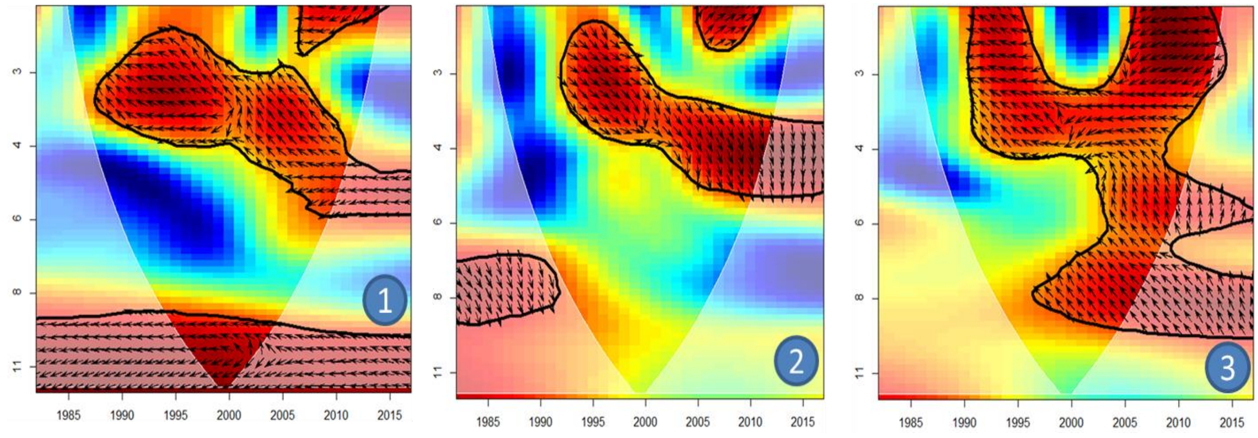

Figure 1.3. Spain.

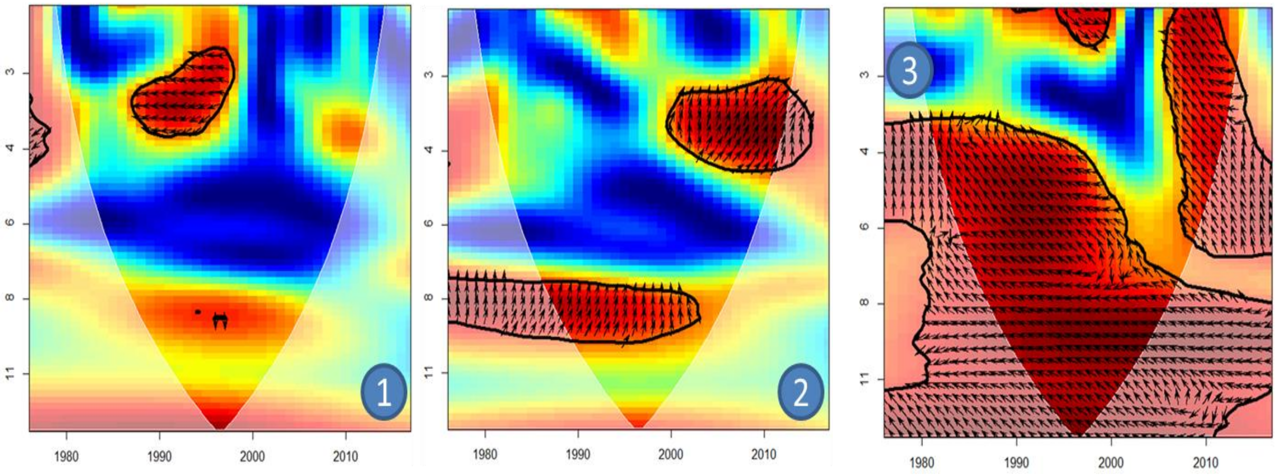

Figure 1.4. Finland.

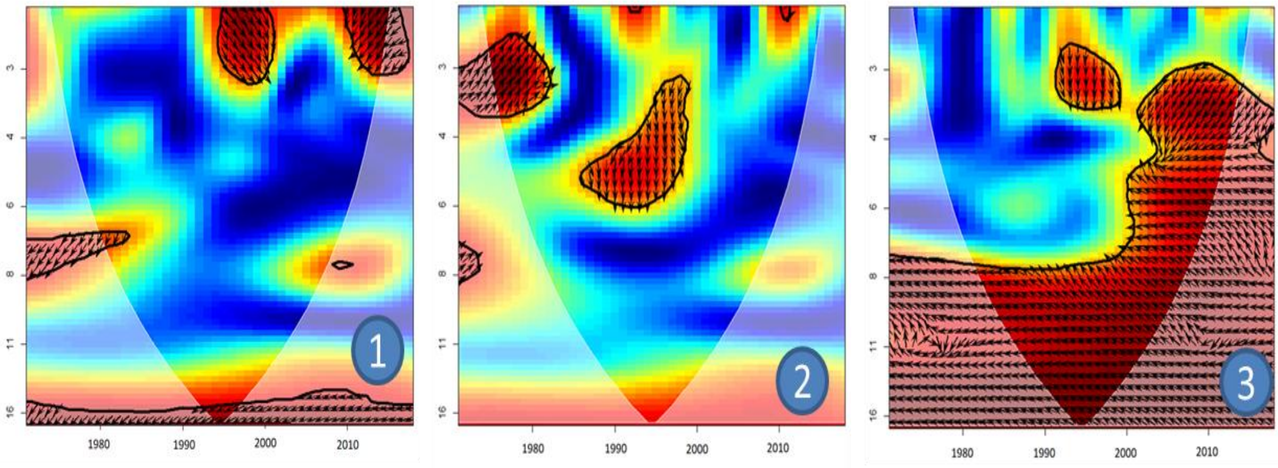

Figure 1.5. France.

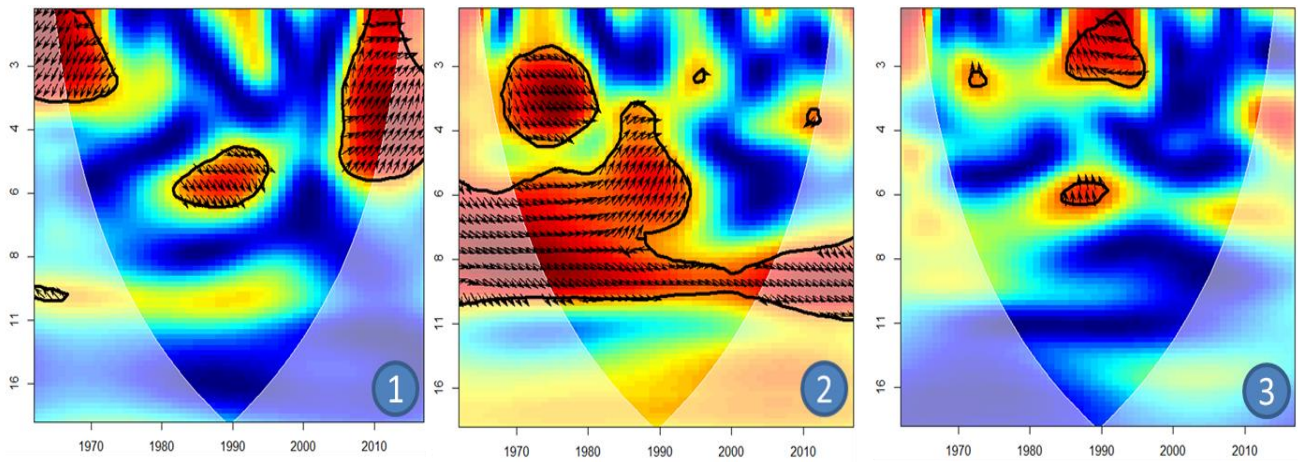

Figure 1.6. Greece.

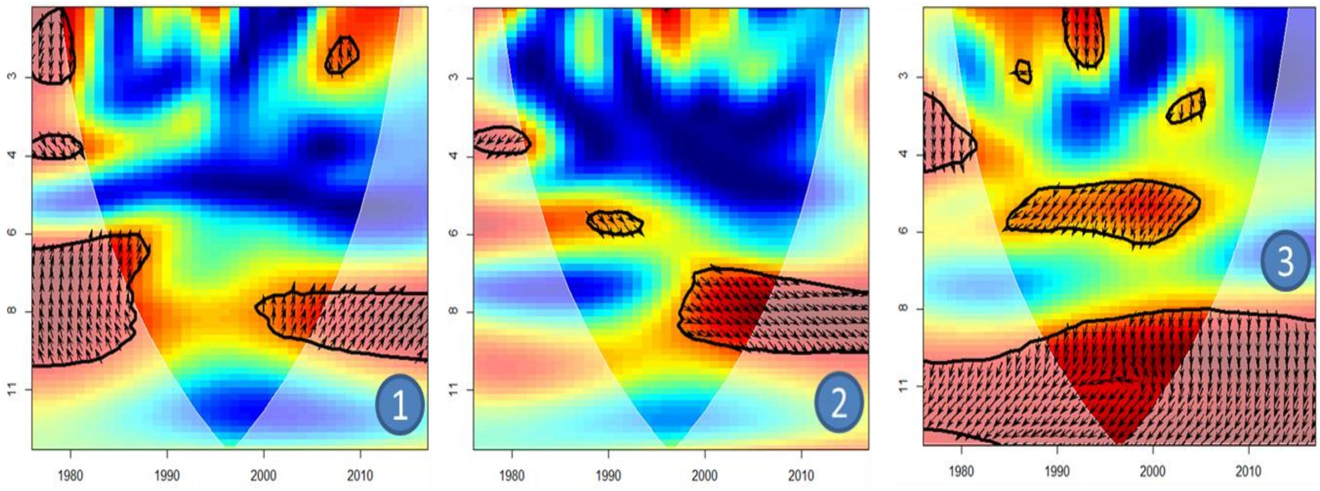

Figure 1.7. Ireland.

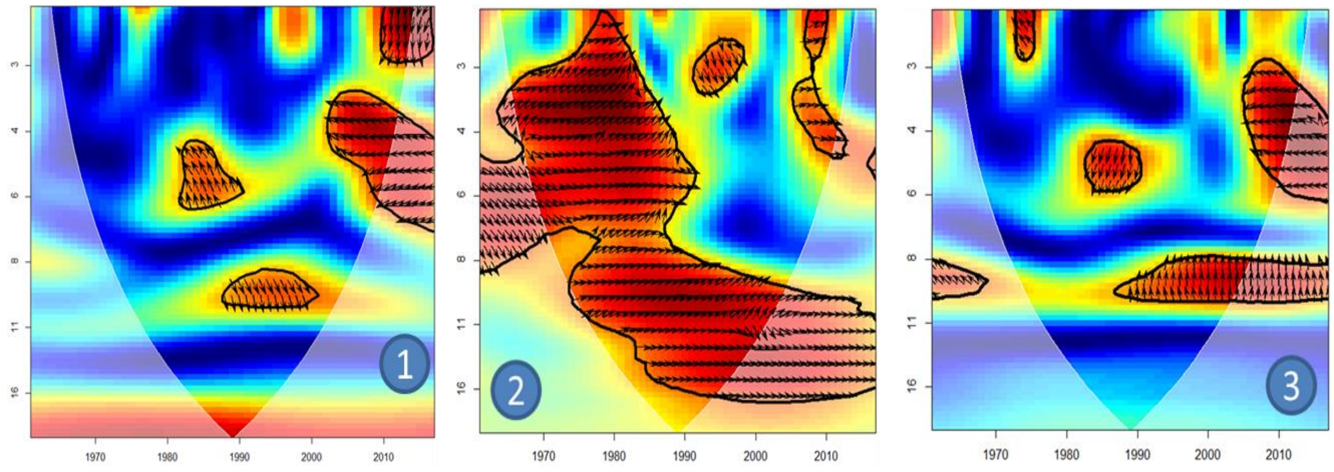

Figure 1.8. Italy.

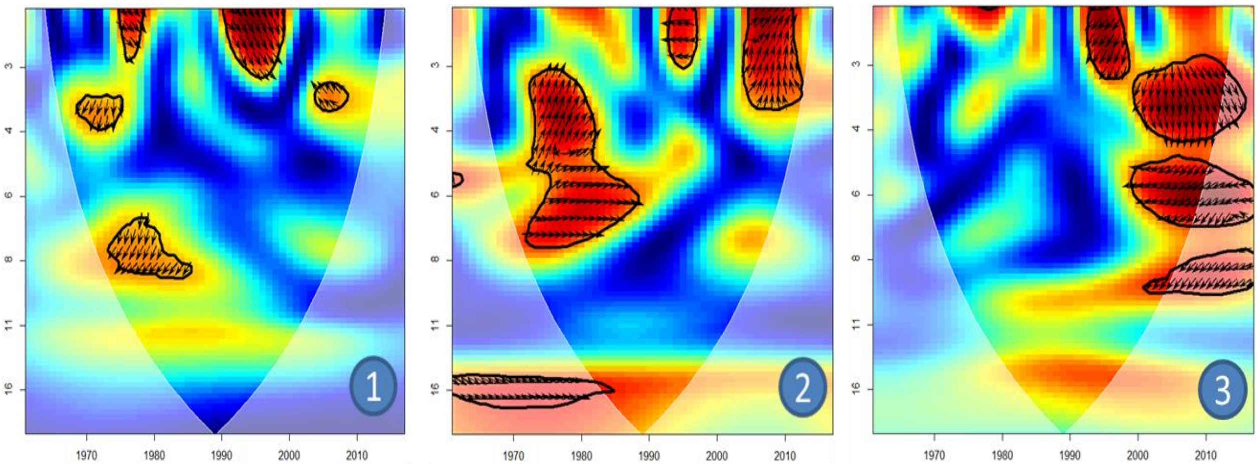

Figure 1.9. Netherlands.

Figures 1. Wavelets Coherence and Phase analysis.

We divide our analysis into two parts. In a first part, we focus on the direct relationship between energy supply and growth to identify the nature of their linkages. In a second part, we study the indirect relationship between energy supply and growth as we consider the debt channel. In this case, we should also study the debt-energy relationship and at the end the debt-growth linkages.

3.1. Direct relationships between energy supply on economic growth

Both in the short and long term, we note a positive correlation from energy supply to growth for Germany, France, and Italy (only at long term for Finland) during the 1980s, confirming the growth hypothesis. Over the same period, similar results are observed for Belgium and the Netherlands, both at short and medium terms, as the energy supply affects growth, while in the long-term, growth dominates the relationship. For these countries, both the growth and conservation hypothesis are observed, leading one to assume a time frequency feedback relationship. Spain is also characterized by a domination of growth in the long term, as well as Greece on all frequencies (confirming the conservation hypothesis). Whatever the direction of the causal relationship, these two variables are in phase, and then move in the same direction for all countries. In the 1990's, there are no medium- and long-term relationships between these variables for Germany, the Netherlands, Spain, Ireland, and France. In this case, the neutral hypothesis is observed at long run, but at short run, we note differences. In France, the energy supply only affects growth in the short run, while we note a feedback relationship in the medium run. At the opposite, for the Netherlands and Spain, growth affects the energy supply only at short run. In Finland and Belgium, the energy supply continues to affect growth at the short (not in Finland) and long term, while a long-term feedback relationship is emerging in Italy and Greece at the short and medium term.

During the 2000s and 2010s, we find no strong relationship between these variables in Belgium, Germany, Finland, the Netherlands, Spain, and France. However, during the 2008–2009 crisis, the energy supply affects the growth in the short term in France, Finland, and the Netherlands. In the case of Spain, a frequency feedback relationship is highlighted, as energy affects growth in the short run, but at medium run, the relation is inverted. A more complex frequency feedback relationship is noted in Italy. There is a long-term feedback relationship, while in short and medium terms, the energy supply still affects growth during the debt crisis in 2011. In Ireland and Greece, a strong long-term relationship has been established since the early 2000s, with growth as the leader. In addition, the domination of energy over growth in the short term is noted during the European debt crisis in Greece.

For peripheral countries (Spain, Italy, Greece, Ireland, and Finland), energy supply is still a leading factor, while the relationship gradually fades during the 1990s for the core European countries (especially at long run). In the case of Italy, growth is fully dependent on the energy supply. Therefore, a negative supply shock leads to slower growth, both in the short and long term. In the long run, there is no clear growth leadership, as a feedback relationship is established. Then, an economic recovery plan would be less inefficient than either policies or measures focused on the energy supply (necessarily a long-term investment). In Spain, a similar negative shock would result in slower growth in the short term. However, as growth largely dominates supply in the medium term, a coherent recovery plan would have a better chance of success than in Italy. On the other hand, in Ireland and Greece, a supply shock does not seem to affect growth, as the neutral hypothesis assumes.

The direct relationship highlights that a policy focused on energy supply is required in Italy, and in a lesser extent, in Greece and Spain, to face a negative energy supply short run shock.

3.2. The Debt channel and Indirect relationships between energy supply on economic growth

The indirect effects between energy and growth implies the existence of a debt channel. In this case, we consider the indirect effect from the energy supply to growth if the energy supply affects debt and if debt affects growth. Following the same logic, the indirect effect from growth to the energy supply is to identify if debt leads energy and if growth leads debt.

These conditions emerged in Italy in the 2000s and after the debt crisis. The energy supply affects debt in the short and medium terms, while there is a feedback debt-growth relationship. Therefore, a negative energy shock increases debt (probably due to higher import costs), which slows the growth. In addition, noting that the direct effect of the energy slows down growth even more. A similar short run relationship is observed in France, as there are both a direct effect of the energy supply on growth (in phase) and an indirect impact on growth via the debt channel (energy supply leads in anti-phase debt). However, at a mid-long run, there is only a feedback relationship (in anti-phase) between debt and growth.

In the medium-term, an indirect effect from the energy to growth appears in Belgium (a negative shock on energy leads to an increase of debt slowing down growth) since the 2000s. In addition, an indirect effect from growth to the energy is observed at the long run until the global financial crisis of 2008 and at the short run ever since (a decrease of growth lead to a decrease of debt and then an increase of energy supply). At the long run, debt seems to be the key factor leading both growth and the energy supply.

In the long term, we notify a singular relationship since the 2000s in Ireland. The energy supply (leader) and debt move in same direction. Then, by reducing its energy supply, it reduces its debt, which accelerates growth. However, this acceleration in growth leads to an increase in the energy supply. This case indicates that Ireland can implement a long run policy to reduce its dependance to energy imports to decrease its debt level, while increasing the domestic energy supply and then increasing growth.

In Spain, we observe a direct long-term effect from the energy to debt (evolution in anti-phase) since the 1990s. However, it seems that if debt does not affect the growth path, then there are no indirect linkages from energy to growth. However, the indirect effect from growth to energy is observed at the mid-run until the 2008 crisis. Greece also highlights a direct effect of energy on debt (in phase) at mid-run during the 1990 decade and at the short-run since 2000, though there are no indirect impacts.

4. Conclusions

In this paper, we study the time frequency dynamics of the relationships between energy and growth to highlight the direct and indirect effects thorough the debt channel. As many eurozone members are dependent to energy products, their energy supply is then a component of debt. The debt channel is then related to the debt-energy supply linkages and the debt-growth relations. Using wavelets, we identify both the intensity and the direction of the relationship between each pair of variables according to periods of economics cycles (short, medium, and long cycles).

Our results suggest that the energy supply is an important factor for countries with a high debt/GDP ratio (Greece, Italy, France, Spain and Belgium), especially since the 2008 and European debt crises, as the debt channel is effective at the mid and long run. As seen with Italy, a feedback relation was highlighted, with both direct effects of the energy supply on growth and debt associated with indirect effects impacting at the medium and long run. As seen with Spain, the direct and indirect relationship between the energy and growth located at different cycles are highlighted. In France, the direct and indirect effects of the energy on growth are only at the short run. In Belgium, despite a direct relationship between growth and energy since 2000s, the debt channel generates a bicausal relationship at the short and mid run. We note that Greece is an exception due to its highest indebtment level. Since the 1990s and the financialization of the Greek economy, the debt increases faster than GPD. However, we note that the energy supply and growth are highly and positively correlated like energy and debt. In Greece, the energy supply should be carefully monitored to avoid a greater debt increase which negatively affect growth.

To conclude, we highlight the complexity of the energy supply-growth relationship to establish an energy transition plan. States should identify their own optimal frequency to meet energy goals, such as the Fit for 55 ambitions while dealing and monitoring the debt channel. In such a case, Italy and Spain clearly need assistance to get out a self-perpetuating, vicious, debt-energy circle at the mid and long run. In a lesser extent, France should monitor their debt-energy relations at the short run. The Finnish case perfectly illustrates that a country with a reasonable debt/GDP ratio is not subject to the indirect effect, as there is no debt channel with the energy supply as a direct effect on growth. German and Dutch situations are similar, as there is no effect or indirect relations between the energy and growth at the mid and long run. For these two countries, the debt-growth linkages highlight a frequency bicausal relationship.

Conflict of interest

All authors declare no conflicts of interest in this paper

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