ENERGY SUPPLY, PUBLIC DEBT, AND ECONOMIC GROWTH: CAUSALITY ANALYSIS FOR A PANEL OF OECD EUROPEAN COUNTRIES

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Introduction

Economists have focused on the importance of growth as it is considered a core government objective and driver of living standards. Economic growth is

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strongly linked to production, energy, debt, the natural environment, and human health. Therefore, countries must be aware of the essential role of economic growth and its impact on economic development and global sustainability. The challenge is how best to integrate these ideas into mainstream policies and consider how they can be effectively implemented to support sustainability goals, which in our research focus is within the context of Europe.

Today, the COVID-19 crisis and the Russian-Ukrainian conflict highlight the importance of energy supply as an eco-political factor due to its role as a catalyst for economic development and its implications on the worldwide economy via public debt levels and inflation rates. The relationship between energy and economic development has captured the attention of both researchers and academia because of its crucial policy ramifications during the past decade. There have been several studies undertaken to determine the causal linkages between energy and economic growth applying various methods such as time-series analysis and panel approaches especially after the seminal work of J. Kraft and A. Kraft in 1978, which is considered as the starting point in this field. Energy plays a critical role in an economy both on the demand and supply sides. On the demand side, energy is one of the commodities that a consumer chooses to purchase to maximize his or her utility. On the supply side, energy is an important input to production, capital, human labor, and materials. In addition, energy supply is considered a vital factor for the economic and social development of countries, where the countries that produce the energy have a high probability of increasing both their economic growth and living standards. Limiting energy supply can lead to negative effects on a nation's development and its economic growth.[1] An energy shortage and inadequate energy supply are essential factors that can adversely impact energy security, economic and social welfare, and increase the costs of production and transportation. The other topic that has been vigorously discussed in the literature is the relationship between public debt expansion and economic growth, which has grabbed the attention of many analysts during recent years stimulated by the sharp increase in public debt after the 2008 financial crisis, especially in the Euro area. Indeed, in response to the financial crisis, governments employed fiscal policies to raise aggregate demand. The consensus among economists is that increases in public debt in the short run, due to fiscal policies, will result in a boost to economic growth. However, there are dissenting views about the long-term impact, some

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economists suggest that there is a negative relationship between public debt and economic growth, while others deny the relationship between these variables in the long term.

The explanation of economic growth—either by debt or by energy—appears to be more complex than an intuitive interpretation of policy makers. Debt is a double-edged sword. On the one hand, it promotes consumption and accelerates capital accumulation, thus contributing to economic growth. On the other hand, by increasing debt servicing costs, it exposes countries to financial risks. A strong expansion of the debt can be associated with a significant economic contraction that can last for years.[2] Whatever the economic situation (expansion or recession), we have noted that for some European OECD countries, the pace of growth is not the same as for others due to their high indebtedness ratios and lack of energy resources,[3] where the pace of GDP growth is affected by energy supply for some countries or by their debt policies for others. Given the financial and economic downturn, the group of European OECD members, especially the ones with weak economies—the so-called GIIPS countries (Greece, Ireland, Italy, Portugal, and Spain)—represent a valuable case for testing the dynamics and relationships of persistently high levels of public deficits and external imbalances. It is, therefore, important to understand the link not only between debt and economic growth but also between energy and economic growth to derive useful policy indications, which are necessary to understand whether a reduction in debt or an increase in energy supply is sufficient to resolve the imbalances.[4] Therefore, the added value of our study lies in taking into account the energy supply for a better three-dimensional explanation between energy, debt, and economic growth, on the one hand, and by splitting the OECD European countries into two sub-samples, GIIPS and Non-GIIPS counties, on the other hand. It would be appropriate to highlight our variables of interest, which are energy supply, public debt, and economic growth, and will be addressed further in the subsequent parts of our article.

First of all, priority must be given to an efficient and sustainable energy supply. Sustainability is no longer limited to the preservation of the environment. According to the OECD, primary energy supply is defined as energy production plus energy imports, minus energy exports, minus international bunkers, then plus or minus stock changes. The International Energy Agency (IEA) energy balance methodology is based on the calorific content of the energy commodities and a common unit of account: 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, but for most forms of natural and manufactured gas the difference is 9% to 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 tons of oil equivalent (toe) and toe per $1.000 USD. Secondly, 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 occur when expenditures, made possible by borrowing, exceed revenues, leading to an increase in the debt. Finally, a country's growth is measured by the increase in its gross domestic product (GDP) over a given period: 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 the GDP indicator, evaluated in constant currency to take into account inflation. This is an indispensable, but not always sufficient, proxy for development. Therefore, gaining a greater understanding of the interactions between these variables is immensely useful for policy formulation.

This paper proceeds as follows. The next section reviews the literature to establish the existing knowledge of the relationships between energy, debt, and economic growth. The methodology section includes details of the model and hypotheses, then the results are analyzed and discussed. Finally, future research directions are suggested.

Brief Literature Review

Energy – Economic Growth: In considering the relationship between energy consumption and economic growth, two opposing views have emerged. One view is that energy consumption limits growth. It also is argued that the potential impact of energy consumption on growth varies with the structure of the economy and the economic growth cycle of the country. Through the development of the economy, its production structure should move toward services, which are not energy-intensive activities, as argued by a group of authors such as E. Denison, B. Cheng, J. Asafu-Adjaye, and R. Solow.[5] The other view implies that energy can be the source and driver of economic growth. The increase of energy consumption is one of the effects of economic growth. Moreover, energy is a key source of economic growth because it multiplies consumption and production activities that involve energy as a basic production factor.[6] From a physical perspective, energy consumption drives economic productivity and industrial growth and is essential to the development of any modern economy.[7]

Broadly speaking, the connections between energy and growth, developed by C. Jumbe, A. Shiu and P.-L. Lam, G. Altinay and K. Erdal, S.-T. Chen et al., P. Mozumder and A. Marathe, J. Squalli, N. Apergis and J. E. Payne, and I. Ozturk and A. Acaravci, have been grouped into four categories, each of which has important implications for energy policy:[8]

(i) The growth hypothesis asserts that there is a unidirectional relationship between energy consumption and economic growth. It argues that energy consumption plays a dominant role in economic growth both as a direct factor in the production process and indirectly as a complement to labor and capital. Energy is considered here as a complementary factor of production to the usual factors such as capital and labor. Under these conditions, the implementation of energy policy influences the level of production, according to E. Yu and J.-Y. Choi, S. Tsani, A. Belke et al., and M. Destek.[9]

(ii) The conservation hypothesis suggests that growth generates an increase in energy consumption. This assumes that a restrictive energy policy can be implemented in an economy without negative effects on growth. If there is a unidirectional Granger causality from growth to energy consumption, this hypothesis is confirmed. Indeed, S. Paul and R. Bhattacharya, A. Hatemi et al., and T. Gelo assert that energy conservation policies can be implemented with little or no negative effects on economic growth.[10]

(iii) The neutrality hypothesis implies that there is no causal relationship between energy consumption and economic growth. These two variables are not correlated. In other words, any increase or decrease in energy consumption does not affect economic growth. This means that neither an energy-saving policy nor an energy-intensive policy influences the level of wealth creation in an economy, as explained by T. Jobert and F. Karanfil.[11]

(iv) The feedback hypothesis states that there is a two-way causality between energy consumption and economic growth. This means that energy and economic policies will be implemented jointly. In this case, the energy consumption policy should be developed to avoid a negative impact of energy consumption on economic growth (studies applied to one or groups of countries: Greece, G7, OECD countries), according to G. Hondroyiannis, C.-C. Lee et al., M. Mutascu, and J. Dos et al.[12]

Thus, empirical studies related to the above-mentioned hypotheses show a unidirectional causality that exists from total energy consumption to economic growth (applied to a group of African countries) concluded by A. Akinlo and S. Solarin.[13] A unidirectional causality in the other direction was concluded by J. Kraft and A. Kraft[14] applied to the United States for a period from 1947 to 1974 and by R. Abaidoo[15] using quarterly data over 39 years. The study by M. Behname found a bidirectional relationship between the two variables.[16] No relationship between energy and growth was concluded by T. Carminel, explaining that the decoupling between energy and growth is limited by concerns about the supply of raw materials.[17] As an example, energy-related technologies needed to extract certain materials are subject to geopolitical constraints. The raw material supply problem, in turn, limits the deployment of the equipment needed to improve energy intensity. U. Erol and E. Yu researched a group of countries to find the causal link between energy consumption and GDP using the Granger and Sims causality tests.[18] They concluded that there was one-way causality between energy consumption and GDP for West Germany, two-way causality in Italy, and a lack of causality between the two variables for France, the United Kingdom, and Canada. A. Masih and R. Masih applied their work to six Asian countries (India, Indonesia, Malaysia, Pakistan, the Philippines, and Singapore) using Johansen's methodology, vector error-correction model, and variance decomposition.[19] The discrepancies in the results are summarized as cointegration between energy consumption and GDP in India, Indonesia, and Pakistan, and non-cointegration between the two variables in Malaysia, Singapore, Pakistan, and the Philippines; energy consumption causing GDP (more energy consumption, more growth) in India; GDP causing energy consumption in Indonesia; and two-way causality in Pakistan. J. Chontanawat et al. assessed the relationship between the two variables on a panel of over 100 countries, including 30 OECD and 78 non-OECD countries, to detect the relationship between energy and growth.[20] Their findings reveal that energy consumption drives GDP (more energy consumption, more growth) in 21 OECD countries. For non-OECD countries, this relationship is found in 36 of the 78 countries or 46%. In summary, a more common causality between energy consumption and GDP is noted for advanced OECD countries. From this point of view, a measure focused on limiting energy consumption would have a greater negative impact on GDP in OECD countries than in non-OECD countries.

I. Ozturk and A. Acaravci sought to test the relationship between energy and growth in four Eastern European countries (Albania, Bulgaria, Hungary, and Romania) over the period 1980-2006 using the Engle and Granger model.[21] They found a lack of causality for Albania, Bulgaria, and Romania; however, a presence of bidirectional causality was observed in Hungary.

Public Debt – Economic Growth: The second strand of literature is related to the relationship between public debt and economic growth. The empirical literature on this topic not only presents ambiguous results but focuses mainly on the possible impact of high debt levels on economic growth, ignoring the possibility of reverse causality from growth to debt, with rare exceptions such as the works of M. Ferreira and M. Puente.[22] However, A. Bell et al. find that there is some theoretical evidence that public debt is likely to accumulate when growth is low.[23] In this regard, since low growth means more limited government revenues, governments may be forced to increase their debt levels to maintain the welfare state, stimulate demand in the short run, and increase growth in the long run, according to M. Feldstein.[24] Theoretically, neoclassical and endogenous growth models, such as those of F. Modigliani, P. Diamond, G. Saint-Paul, and J. Aizenman et al., suggest that high levels of public debt would undeniably reduce the rate of economic growth.[25] Other channels to support the negative effect of public debt on long-run growth include the debt overhang hypothesis (P. Krugman and N. Roubini et al.),[26] the liquidity constraint hypothesis (T. Moss and H. Chiang),[27] the crowding-out hypothesis (H. Hansen),[28] and the uncertainty hypothesis (L. Codogno et al. and J. Cochrane).[29] Another channel through which high debt can negatively impact growth is through long-term interest rates (D. Elmendorf and G. Mankiw, V. Tanzi and N. Chalk).[30] Finally, some of the effects associated with financial liberalization, ranging from increased risk-taking by banks to the accumulation of large external debt, can make a country vulnerable to economic shocks that often can have severe recessionary consequences (B. Eichengreen and D. Leblang, U. Nyambuu and L. Bernard).[31] Given the theoretical predictions highlighted above, it is somewhat surprising that C. Reinhart and K. Rogoff concluded that a country's debt must reach a threshold of 90% of GDP, beyond which the rate of GDP growth declines significantly, has generated such controversy.[32] Other researchers have strongly criticized this by noting that over the period 1946-2009, countries with a debt-to-GDP ratio above 90% had an average annual real GDP growth of 2.2% not -0.1%.

Additional empirical studies have shown the relationship between debt and growth. C. Checherita-Westphal and P. Rother analyzed the average impact of public debt on GDP per capita growth in 12 euro area countries over about 40 years, starting in 1970.[33] They conclude that there is a non-linear effect of debt on growth with a turning point beyond which the ratio of public debt to GDP harms growth in the long run at around 90/100% of GDP. U. Panizza and A. Presbitero studied the causal effect of government debt on economic growth in a sample of OECD countries.[34] Their results are consistent with the existing literature, showing a negative correlation between the two variables. J. Mencinger et al. empirically analyzed the relationship between the ratio of government debt to GDP and GDP growth on a panel dataset of 25 European Union (EU) countries.[35] To take into account the impact of the level of the debt-to-GDP ratio on the real GDP growth rate, they used panel estimation on a generalized economic growth model augmented with a debt variable, while also considering some methodological issues such as heterogeneity and endogeneity problems. The results of all models indicate a statistically significant non-linear impact of government debt ratios on annual growth rates of GDP per capita. Their research has contributed to a better understanding of the problem of high public debt and its effect on economic activity in the EU.

The debt-growth and energy-growth relationships have been discussed in the literature, which leads us to look at the decoupling of growth and energy, on the one hand, and the problem of public debt in OECD European countries, on the other. These two facts raise a fundamental question: What can be said about the links between energy, debt, and GDP? The question is crucial today because we are exposed to many challenges. The current fall in the global growth rate and its consequences are the subjects of much debate. Is it due to pressure on energy resources? Is the high level of public debt related to the link between energy and economic growth? All of these issues spur greater interest in determining the potential econometric short- and long-term relationships between energy, debt, and growth.

Model and Methodology

Model: Based on our brief literature review, and to achieve the study's objective, we form a long-run relationship between economic growth, energy supply, and public debt in a linear logarithmic form as follows in equation (1):

$$EGR_{it} = \alpha_0 + \beta_1 ESU_{it} + \beta_2 PDE_{it} + u_{it} \quad (1)$$

Where $i = 1, \ldots,$ N (number of the chosen countries) denotes the country; $t = 1, \ldots,$T denotes the time period from 1970 to 2021; u_{it} is assumed to be a serially uncorrelated error term; α_0 represents the constant in our model; *EGR* represents the economic growth, which is our dependent variable; and *ESU* and *PDE* represent the energy supply and the public debt, respectively, which are our independent variables. The expected signs of energy supply and public debt are positive and negative, respectively, meaning that energy supply and public debt have, respectively, a positive and negative impact on economic growth in the long term.

Cointegration Methodology: To test the existence of a long-run relationship among the variables and to capture the short-run dynamics of the variables using the vector error-correction model (VECM), our methodological strategy is composed of two essential steps.

The first step is to verify the order of integration for all variables because the several cointegration tests are valid only if all the study's variables are integrated in the same order, meaning that they have the same order of integration. We test the stationarity using four different types of unit root tests divided into common and individual unit root: Levin, Lin, and Chu (LLC); Im, Pesaran, and Shin (IPS); a Fisher-type test using Augmented Dickey-Fuller (ADF); and Phillips-Perron (PP). In 1997, H. Zapata and A. Rambaldi[36] reported that if the variables are not integrated in the same order (meaning that some variables are I(0) and the others are integrated of order one I(1)), the application of Toda and Yamamoto (TY) is required to be on the safe side and to overcome this problem, whereas the TY procedure does not impose any prerequisites and knowledge on cointegration.

The second step requires testing the panel cointegration relationship. When all series and variables are integrated into the same, we can move on to test the panel cointegration between the variables based on the three fundamental tests: Pedroni; Kao; and Johansen Fisher. The Pedroni and Kao tests are based on the Engle-Granger two-step (residual-based) cointegration test. Overall, Pedroni provides seven statistics to test the null hypothesis of no cointegration in the heterogeneous panels. These seven tests can be categorized as either within-dimension (panel tests) or between-dimension (group tests). These tests are all based on the residuals from equation (1) and are variants of the ADF and PP tests. The within-dimension tests pool the autoregressive coefficients across different members of the panel. On the other hand, the between-dimension tests are less restrictive than the within-dimension tests in the sense that they allow for the heterogeneity of the parameters across countries. Kao's test follows the same basic approach as Pedroni's tests but specifies cross-section-specific intercepts and homogeneous coefficients in the first step. In addition, the Fisher test is a combined Johansen and Juselius test. If cointegration exists between the variables, the ordinary least squares (OLS) method is applied to ensure that the estimation of equation (1) does not lead to a spurious regression result. In addition, the parameters estimated by the OLS method are super consistent.

Granger Causality: Then, we look forward to examining the existence and the direction of the causality between the variables in a panel context. The existence of cointegration implies that there are long-run equilibrium relationships between the variables and, thus, Granger causality between them in at least one direction. The vector error-correction model (VECM) is used to correct the disequilibrium in the cointegrating relationship, captured by "ECT," as well as to test for long- and short-run causality between the cointegrated variables. The VEC model by definition is a restricted VAR that has cointegration restrictions built into the specification so it is designed for use with nonstationary series that are known to be cointegrated. The VEC specification restricts the long-run behavior of the endogenous variables to converge to their cointegrating relationships while allowing a wide range of short-run dynamics. The cointegration term is known as the error-correction term since the deviation from long-run equilibrium is corrected gradually through a series of partial short-run adjustments. The panel-based VECM is defined as follows in equation (2):

$$\begin{bmatrix} \Delta EGR_{it} \\ \Delta ESU_{it} \\ \Delta PDE_{it} \end{bmatrix} + \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \end{bmatrix} + \sum_{p=1}^{r} \begin{bmatrix} \beta_{11p} & \beta_{12p} & \beta_{13p} \\ \beta_{21p} & \beta_{22p} & \beta_{23p} \\ \beta_{31p} & \beta_{32p} & \beta_{33p} \end{bmatrix} \begin{bmatrix} \Delta EGR_{it-p} \\ \Delta ESU_{it-p} \\ \Delta PDE_{it-p} \end{bmatrix} + \begin{bmatrix} \theta_1 \\ \theta_2 \\ \theta_3 \end{bmatrix} ECT_{it-1} + \begin{bmatrix} \varepsilon_{1it} \\ \varepsilon_{2it} \\ \varepsilon_{3it} \end{bmatrix} \quad (2)$$

Where $i = 1, \ldots,$ N (number of the chosen countries) denotes the country; $t = 1, \ldots,$T denotes the time period from 1970 to 2021; ε_{it} is assumed to be a serially uncorrelated error term; and *ECT* is the lagged error-correction term derived from the long-run cointegration relationship. We follow Abdalla and Murinde's process to determine the optimal lag length in each equation for a linear system which is selected by maximizing the value of the R-squared (R^2) and minimizing the AIC criteria. In terms of causality, we test four main hypotheses that sum up all the cases between the three chosen variables as follows:

H_1: Unidirectional causality relation from variable 1 to variable 2 (Meaning that the first variable does Granger causes the second one).
H_2: Unidirectional causality relation from variable 2 to variable 1 (Meaning that the second variable does Granger causes the first one).
H_3: Bidirectional causality relation between variable 1 and variable 2 (Meaning that both variables do Granger cause each other).
H_4: No causality relation between both variable 1 and variable 2 (Meaning that the first variable does not Granger causes the second variable).

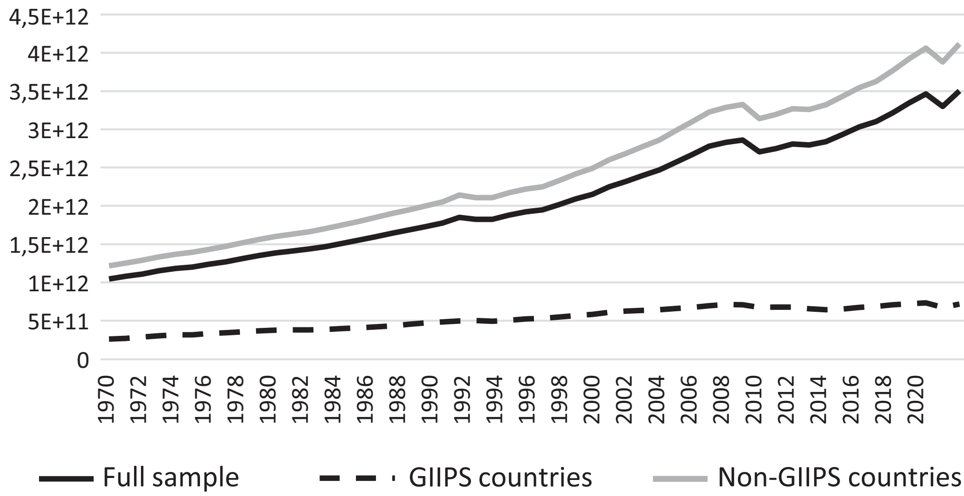
Empirical Results

Data Analysis: In this paper, we have conducted a statistical and econometrical analysis of 21 OECD European countries for which the most energy-related and macroeconomic annual data are available from 1970 to 2021. The 21 countries include the 5 GIIPS (Greece, Ireland, Italy, Portugal, Spain) and the 16 Non-GIIPS (Germany, Belgium, Finland, France, Netherlands, Luxembourg, Austria, Denmark, Poland, Hungary, Sweden, Switzerland, Norway, England, Iceland, and Turkey). The objective was to select the largest and the longest balanced panel. The full sample is divided into two sub- samples: GIIPS and the Non-GIIPS. Thus, we construct three different models (balance panel) for the analysis. The data come from OECD's *Economic Outlook No 110-December 2021* (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's *Economic Outlook No 73-June 2003* for all the countries selected to have the largest observations possible (data calibration between two data sources).

Figures 1-3 show the changing trends for each series of the OECD European countries (Full sample, GIIPS, and Non-GIIPS countries). Figure 1 shows that the full sample and Non-GIIPS countries have shown the same significant increase in economic growth all over the period (1970-2021). Whereas the series for the other sample (GIIPS countries) show an almost monotonic increase over the entire time span. In term of economic growth, we can notice that the full sample is well presented by the Non-GIIPS countries.

Figure 2 represents the evolution of energy supply from 1970 to 2021 for the three samples. Overall, we observe that the series have almost the same trend; however, there were two impactful events. The first was marked by the response of energy supply following the financial crisis of 2008, where we find the effect to be

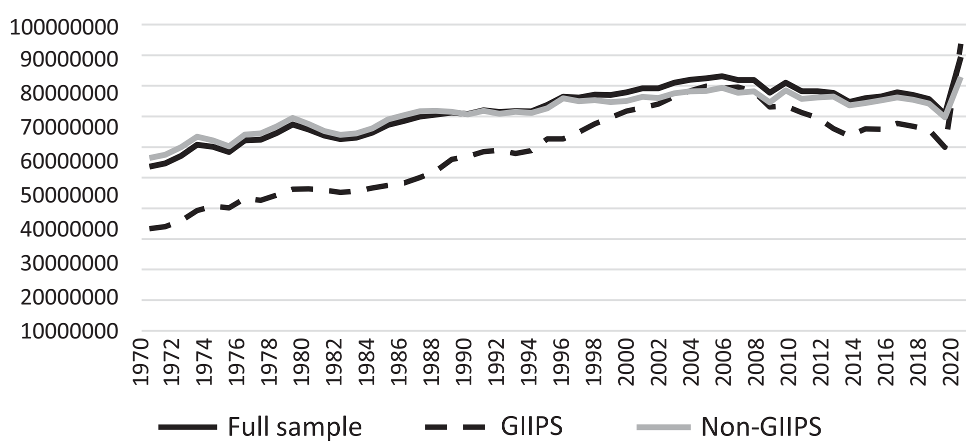
Figure 1
ECONOMIC GROWTH: AVERAGE FOR GDP PER YEAR, 1970–2021



Source: Authors.

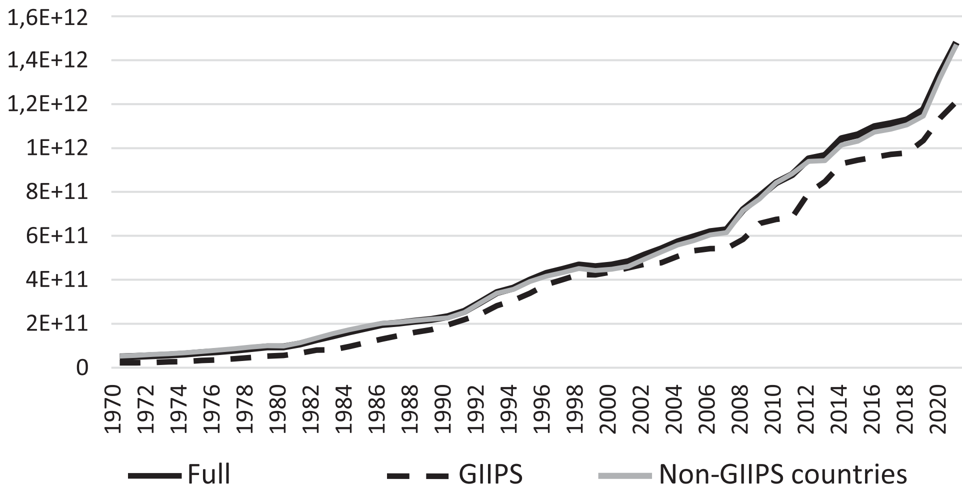
more pronounced for the GIIPS (countries with low growth and high debt as already discussed in the literature). The second event was in regard to the COVID-19 crisis, which favored the GIIPS countries as their energy supply was improved in comparison to the other two samples (full sample and non-GIIPS countries).

Figure 2
ENERGY SUPPLY: AVERAGE PER YEAR, 1970–2021



Source: Authors.

Figure 3
ENERGY SUPPLY: AVERAGE PER YEAR, 1970–2021



Source: Authors.

The trend for public debt is presented in Figure 3. The graph shows that all three series have the same upward trend reflected in an excessive increase in debt levels, mainly in response to three important events: the 2008 financial crisis; the sovereign debt crisis (2011); and the COVID-19 crisis (2019).

Descriptive Statistics and Correlation Matrix: We present the summary of descriptive statistics of the study's variables as shown in table 1. The mean of economic growth in the full sample is equal to 27.16 and ranges from 23.10 to 31.36, which are the same minimum and maximum values for the Non-GIIPS countries. We have recognized that the energy supply and public debt have a difference in the mean between the GIIPS countries and the Non-GIIPS countries. The results ensure the energy supply and public debt vary between the GIIPS countries and the Non-GIIPS countries, indicating the need to split the full sample into two subsamples to capture the difference.

We present the Pearson correlation coefficients among the study's variables in Table 2. The correlation between economic growth and energy supply is negative and significant at 1% while there is a positive and significant correlation between economic growth and public debt. The result supports the hypothesis according to which there is a positive relationship between economic growth and public debt and a negative relationship between economic growth and energy supply. Regarding the correlation between the energy supply and public debt, the results indicate a strong positive relationship between these two variables.

Table 1
DESCRIPTIVE STATISTICS[a]

Variables	Mean	Median	Min	Max	Std. Dev.	No. of Obs.
			Full Sample			
EGR	27.16812	27.24722	23.10801	31.36414	1.491998	1,092
ESU	16.9409	17.30243	10.83985	19.71831	2.138101	1,092
PDE	25.91719	26.1166	19.08927	28.91897	1.647482	1,092
			GIIPS Countries			
EGR	26.40955	26.0062	24.1153	28.21585	1.114771	260
ESU	17.3481	17.01438	15.56645	19.08631	1.090601	260
PDE	25.44128	25.53252	19.08927	28.81175	1.938355	260
			Non-GIIPS Countries			
EGR	27.40517	27.52745	23.10801	31.36414	1.516219	832
ESU	16.81364	17.34393	10.83958	19.71831	2.358597	832
PDE	26.06592	26.24476	10.85372	28.91897	1.516368	832

[a] Min= minimum; Max = maximum; Std. Dev. = standard deviation; No. of Obs. = number of observations.

Panel Unit Root and Panel Cointegration Tests: The time-series properties of the variables in Eq. (1) are checked through four types of panel unit root tests: LLC, IPS, ADF, and PP tests. The panel unit root test is based on the null hypothesis to prove the existence of the unit root, while the alternative hypothesis indicates the absence of the unit root. (H_0: Data are not stationary (Unit root exists) and H_1: Data are stationary (Unit root does not exist)). We apply the common unit root test by using the LLC and the individual unit root by applying IPS, ADF, and PP. The results as shown in table 3 indicate that all the series in Eq (1) appear to contain a panel unit root in their level while stationary in their first difference, showing that they are integrated at order one I (1).

Table 2
CORRELATION MATRIX[a]

	Economic Growth	Energy Supply	Public Debt
EGR	1.0000		
ESU	−0.0564* (0.0626)	1.0000	
PDE	0.5888*** (0.0000)	0.2355*** (0.0000)	1.0000 1.0000

[a] Numbers in parentheses = p-values; * indicates significance at 10%; ** indicates significance at 5%; and *** indicates significance at 1%.

Table 3
PANEL UNIT ROOT TESTS[a]

	Common Unit Root			
	LLC		IPS	
Variable	**Level**	**1st Diff.**	**Level**	**1st Diff.**
EGR	23.223 (1.0000)	−12.760*** (0.0000)	1.064 (0.8564)	−22.459*** (0.0000)
ESU	6.043 (1.0000)	−26.521*** (0.0000)	−2.856*** (0.0021)	−26.108*** (0.0000)
PDE	15.046 (1.0000)	−11.476*** (0.0000)	0.326 (0.6278)	−19.636*** (0.0000)
	Individual Unit Root			
	ADF		**PP**	
	Level	**1st Diff.**	**Level**	**1st Diff.**
EGR	0.4149 (1.0000)	−12.449*** (0.0000)	0.0641 (1.0000)	−14.413*** (0.0000)
ESU	7.931 (1.0000)	−26.474*** (0.0000)	8.943 (1.0000)	−27.510*** (0.0000)
PDE	1.927 (1.0000)	−13.188*** (0.0000)	1.238 (1.0000)	−16.007*** (0.0000)

[a] Numbers in parentheses = p-values; * indicates significance at 10%; ** indicates significance at 5%; and *** indicates significance at 1%.

According to the findings from the panel unit root test, the cointegration between economic growth, energy supply, and public debt can be investigated. For that, we apply the panel cointegration test between economic growth and its determinants by using the Pedroni test, Kao test, and Fisher test. (H_0: there is no cointegration and H_1: there is cointegration). The results are provided in table 4.

Based on the Pedroni test results, we find that 9 out of 11 of the results are significant at 1%, and this is an indicator of panel cointegration. After applying the Kao test, the results indicate the existence of panel cointegration where it is significant at 1%. Additionally, the Johansen Fisher test reveals the existence of two cointegration vectors at 1%. We can summarize that there is strong statistical evidence of panel cointegration among our variables: economic growth (EGR), energy supply (ESU), and public debt (PDE). The existence of cointegration among the variables attempts to exclude the possibility of having a bias in the equation.

VEC-Model and Panel Causality Tests: The time series of our model must be stationary in a long-run analysis to avoid dummy results. For that, before examining the panel cointegration, all variables (economic growth, energy supply, and

Table 4
PANEL COINTEGRATION TESTS[a]

Pedroni Test		
Test statistics	**Statistics (*p-value*)**	**Weighted statistic (*p-value*)**
Alternative hypothesis: Common AR coefs. (within-dimension)		
Panel v-stat	0.224690 *(0.4111)*	−0.773904 *(0.7805)*
Panel rho-stat	−6.756258*** *(0.0000)*	−6.738820*** *(0.0000)*
Panel PP-stat	−8.899870*** *(0.0000)*	−9.365574*** *(0.0000)*
Panel ADF-stat	−8.517234*** *(0.0000)*	−9.151758*** *(0.0000)*
Alternative hypothesis: Individual AR coefs. (between dimension)		
Group rho-stat	−6.120249*** *(0.0000)*	
Group PP-stat	−12.62997*** *(0.0000)*	
Group ADF-stat	−11.65244*** *(0.0000)*	
Kao Test	**t-Statistic**	
ADF	−8.623625*** *(0.0000)*	
Fisher Test	**Trace test**	**Maximum Eigen Value**
Null hypothesis		
r = 0	301.8*** *(0.0000)*	215.8*** *(0.0000)*
r ≤ 1	161.0*** *(0.0000)*	138.0*** *(0.0000)*
r ≤ 2	77.83*** *(0.0006)*	77.83*** *(0.0000)*

[a] *, **, and *** indicate the rejection of the null hypothesis at 10%, 5%, and 1% level of significance, respectively. r denotes the number of cointegration equations.

public debt) must be integrated into order one. Table 5 provides the short- and long-run equilibrium results for the full sample.

The VEC model for the dependent variable EGR is as follows:

$$D(EGR) = -0.53208^{***} - 0.13937^{***} EGR_{(-1)} - 0.00000283 ESU_{(-1)} \\ - 0.0000184 ESU_{(-2)} - 0.00000591 PDE_{(-1)} - 0.00000334 PDE_{(-2)}$$

$$EGR_{(-1)} = 0.00000677^{***} ESU_{(-1)} - 0.00000688^{***} PDE_{(-1)}$$

The result in the equation shows in the short run there is no impact of energy supply and public debt on economic growth in the first equation. However, in the third model where the public debt is the dependent variable, the coefficient of adjustment is negative and significant at 1%. Contrarily, in the long run, both energy supply and public debt are significant at 1%. The impact of energy supply is positive and significant by 0.00000677 on economic growth while there is a negative and significant impact of public debt on economic growth by 0.00000688.

Table 5

VEC MODEL: SHORT- AND LONG-RUN EQUILIBRIUM FOR THE FULL SAMPLE[a]

Dep. Var.	**Source of causation (independent variables)**							**R^2**
	Short-run equation							
	F-statistics							
	ECT	**$\Delta EGR_{(-1)}$**	**$\Delta EGR_{(-2)}$**	**$\Delta ESU_{(-1)}$**	**$\Delta ESU_{(-2)}$**	**$\Delta PDE_{(-1)}$**	**$\Delta PDE_{(-2)}$**	
ΔEGR	−0.53208***	−0.13937***	−0.13352***	−2.83E-06	−1.84E-05	−5.91E-06	−3.34E-06	0.3522
ΔESU	129.9695	29.9088	−10.8347	−0.3188***	−0.0117	0.0572**	−0.0015	0.1048
ΔPDE	−288.7375***	129.1592	168.0498	−0.0280	−0.0230	−0.1463***	−0.1714***	0.0471
	Long-run equation							
	t-statistics							
	$\Delta EGR_{(-1)}$	**$\Delta ESU_{(-1)}$**	**$\Delta PDE_{(-1)}$**					
ECT	1.0000	6.77E-06***	−6.88E-06***					

[a] Dep. Var. = dependent variable; *, ** and *** indicate the level of significance at 10%, 5% and 1%, respectively.

Table 6
PANEL GRANGER CAUSALITY TEST FOR THE FULL SAMPLE[a]

Null hypothesis	No. of Obs.	F-Statistic	P-value
ESU does not Granger cause EGR	1050	9.99874***	5.E-05
EGR does not Granger cause ESU		11.4395***	1.E-05
PDE does not Granger cause EGR	1050	1.79728	0.1663
EGR does not Granger cause PDE		13.9026***	1.E-06
PDE does not Granger cause ESU	1050	10.1356***	4.E-05
ESU does not Granger cause PDE		5.68112***	0.0035

[a] No. of Obs. = number of observations; *, ** and *** indicate the level of significance at 10%, 5% and 1%, respectively.

In the long run, the results indicate for every 1% increase in the energy supply, there will be an increase in the economic growth by 0.000677%. The results also indicate that for every 1% increase in the public debt there will be a decrease in the economic growth by 0.000688%.

The existence of a panel long-run cointegration relationship among economic growth, energy supply, and public debt suggests that there is Granger causality in at least one direction. The balanced panel Granger causality results are presented in table 6. We have divided our work into three samples to provide a more in-depth analysis between the GIIPS and Non-GIIPS countries. After applying the panel Granger causality test for the full sample, the results show unidirectional causality from public debt to economic growth, while there is bidirectional causality from energy supply to economic growth, economic growth to energy supply, economic growth to public debt, public debt to energy supply, and energy supply to public debt.

To permit the use of the Granger causality test for the GIIPS countries, we have applied the VEC model. The results, shown in table 7, indicate there is a negative and significant impact of 1% of energy supply on economic growth, where every 1% increase in energy supply will decrease the economic growth in the long run by 38.63%. For the public debt, the results demonstrate there is a negative and significant impact of 1% of public debt on economic growth in the long run, where every 1% increase in public debt will decrease the economic growth by 70.70%.

As can be seen in table 8, the panel Granger causality test for the GIIPS countries demonstrates there is unidirectional causality from energy supply to economic growth, from economic growth to energy supply, from public debt to economic growth, and from public debt to energy supply, while there is bidirectional causality from economic growth to public debt, and energy supply to public debt.

Table 7

VEC MODEL: SHORT- AND LONG-RUN EQUILIBRIUM FOR THE GIIPS COUNTRIES[a]

Dep. Var.	**Source of causation (independent variables)**							**R^2**
	Short-run equation							
	F-statistics							
	ECT	**$\Delta EGR_{(-1)}$**	**$\Delta EGR_{(-2)}$**	**$\Delta ESU_{(-1)}$**	**$\Delta ESU_{(-2)}$**	**$\Delta PDE_{(-1)}$**	**$\Delta PDE_{(-2)}$**	
ΔEGR	0.005409***	0.365950***	0.156006*	−0.066823	0.003312	−0.007864	0.020506	0.1614
ΔESU	0.012910**	−0.358241**	0.610836***	−0.394976*	−0.026784	−0.007611	0.009621	0.0816
ΔPDE	0.053573***	−0.333889	−0.186522	−0.105665	−0.186808	0.139021**	0.081984	0.0819
	Long-run equation							
	t-statistics							
	$\Delta EGR_{(-1)}$	**$\Delta ESU_{(-1)}$**	**$\Delta PDE_{(-1)}$**					
ECT	1.0000	−0.386387***	−0.707003***					

[a] Dep. Var. = dependent variable; *, ** and *** indicate the level of significance at 10%, 5% and 1%, respectively.

Table 8
PANEL GRANGER CAUSALITY TEST FOR THE GIIPS COUNTRIES[a]

Null hypothesis	No. of Obs.	F-Statistic	P-value
ESU does not Granger cause EGR	250	2.23562	0.1091
EGR does not Granger cause ESU		1.30216	0.2738
PDE does not Granger cause EGR	250	0.23344	0.7920
EGR does not Granger cause PDE		12.5350***	7.E-0.6
PDE does not Granger cause ESU	250	1.04650	0.3527
ESU does not Granger cause PDE		11.2017***	2.E-05

[a] No. of Obs. = number of observations; *, ** and *** indicate the level of significance at 10%, 5% and 1%, respectively.

The same procedure follows to test the Granger causality test for the Non-GIIPS countries. Table 9 provides the VEC model short- and long-run equations for the Non-GIIPS, and the results indicate a long-run relationship. The impact of energy supply has a positive and significant impact of 1% on the economic growth, where the increase of 1% of energy supply will increase the economic growth by 64.04%; while the impact of public debt on economic growth is negative and significant at 1%, where any increase of 1% of public debt will decrease the economic growth by 11.005%.

The panel Granger causality test for Non-GIIPS countries, as can be seen in table 10, demonstrates there is just unidirectional causality from public debt to economic growth, while there is bidirectional causality from energy supply to economic growth, from economic growth to energy supply, from economic growth to public debt, from public debt to energy supply, and energy supply to public debt.

We recognize that the panel causality relations for the Non-GIIPS countries follow the same path as the full sample, caused by the fact that the Non-GIIPS countries represent three-quarters of the full sample. Based on the strong causality results, evidence shows that economic growth does Granger cause public debt, while public debt does not Granger cause economic growth. We can conclude that economic growth can attract the public debt in the full sample, GIIPS, and Non-GIIPS countries. Moreover, the causality runs from energy supply to public debt and public debt to energy supply in the full sample and the Non-GIIPS countries. In the GIIPS countries, the direction is not reversed, where the causality is unidirectional. Nevertheless, the results indicate that the development of energy is a key factor for domestic economic growth, which is an essential factor for the energy supply. Both economic growth and energy supply depend on each other due to a bidirectional causality relationship. Figure 4 provides a visual overview of the panel causality relationships in our study. Our results are in line with the findings of C. Checherita-Westphal and P. Rother.[37] They find that public debt has a

Table 9

VEC MODEL: SHORT- AND LONG-RUN EQUILIBRIUM FOR THE NON-GIIPS COUNTRIES[a]

Dep. Var.	**Source of causation (independent variables)**							**R^2**
	Short-run equation							
	F-statistics							
	ECT	**$\Delta EGR_{(-1)}$**	**$\Delta EGR_{(-2)}$**	**$\Delta ESU_{(-1)}$**	**$\Delta ESU_{(-2)}$**	**$\Delta PDE_{(-1)}$**	**$\Delta PDE_{(-2)}$**	
ΔEGR	−0.001581***	0.257541	0.144308	0.033658	−0.064739**	−0.005236	0.005667	0.1425
ΔESU	0.002676***	−0.316063**	0.251094***	0.019722**	0.039701	0.003066	0.015695	0.0433
ΔPDE	0.017706	−0.247384***	0.159324***	−0.086160	0.059519	0.104183	0.031107	0.0565
	Long-run equation							
	t-statistics							
	$\Delta EGR_{(-1)}$	**$\Delta ESU_{(-1)}$**	**$\Delta PDE_{(-1)}$**					
ECT	1.0000	0.640416***	−1.100575***					

[a] Dep. Var. = dependent variable; *, ** and *** indicate the level of significance at 10%, 5% and 1%, respectively.

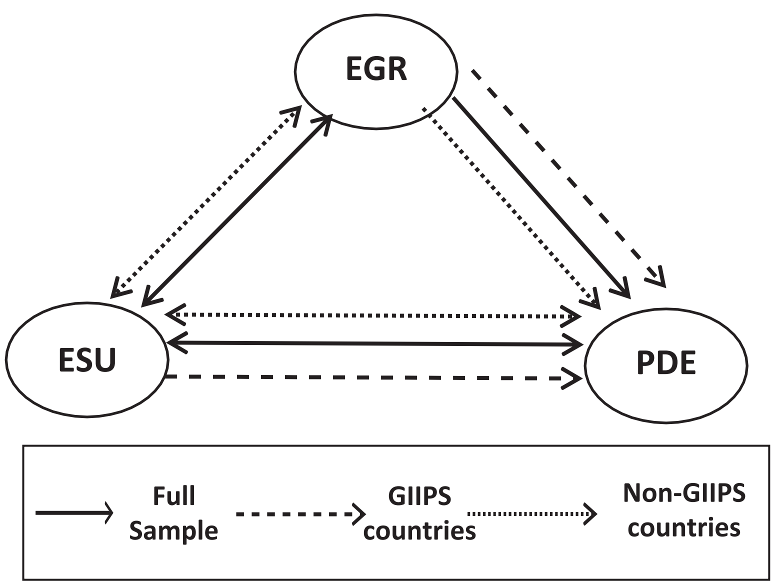
Table 10
PANEL GRANGER CAUSALITY TEST FOR THE NON-GIIPS COUNTRIES[a]

Null hypothesis	No. of Obs.	F-Statistic	P-value
ESU does not Granger cause EGR	800	9.09218***	0.0001
EGR does not Granger cause ESU		5.91700***	0.0028
PDE does not Granger cause EGR	800	0.81032	0.4451
EGR does not Granger cause PDE		8.48876***	0.0002
PDE does not Granger cause ESU	800	5.45424***	0.0044
ESU does not Granger cause PDE		2.96195*	0.0523

[a] No. of Obs. = number of observations; *, ** and *** indicate the level of significance at 10%, 5% and 1%, respectively.

negative effect on economic growth in the long term. The findings are also somewhat consistent with those of U. Panizza and A. Presbitero, who reported evidence of a negative correlation between government debt and economic growth.[38] In contrast, in 2009, M. Ferreira, using OECD annual data for 20 countries from 1988 to 2001, finds evidence of a clear bidirectional Granger causality relationship between economic growth and public debt.[39]

Figure 4
PANEL CAUSALITY RELATIONS



Conclusions

In this article, we analyze the impact of energy supply and public debt on economic growth taking the European countries as a case study during 1970-2021 by applying a panel approach. To achieve added value in our research, we divided our sample into GIIPS countries (which are the weaker economies of Greece, Ireland, Italy, Portugal, and Spain) and Non-GIIPS countries. In addition, previous articles focused on energy consumption and its impact on economic growth; however, these researchers did not pay attention to energy supply, which elevates the value of our study. The main findings for the GIIPS countries are the non-evidence of a causal relationship between energy supply and economic growth. These two variables are not correlated. In other words, any increase or decrease in energy supply does not affect economic growth. This means that neither an energy-savings policy nor an energy-intensive policy influences the level of wealth creation in the economy. Regarding the two other samples (full and Non-GIIPS), we found a two-way causality between energy supply and economic growth. This means that energy and economic policies will be implemented jointly. In this case, the energy supply policy should be developed as an essential factor to attain higher levels of economic growth in the long term while avoiding its negative impact in the short term. In addition, there is a negative relationship between public debt and economic growth in full, GIIPS, and Non-GIIPS countries. In regard to causality, there is unidirectional causality from economic growth to public debt. Thus, the European countries should consider the accumulation of government liabilities as a main issue due to the fact that public debt, in the long term, will deactivate the wheels of the economy and disrupt economic growth. Governments in European countries have to perceive the importance of public debt and energy supply as part of their public policy and they should be aware that the public debt is a double-edged sword. The governments' strategic priorities should focus more on energy supply, especially renewable energy sources, and other economic factors that can stimulate economic growth as a way of combatting public debt in the long run. Moreover, in terms of energy, it would be useful for future research papers to include in their modeling the primary energy consumption that represents the demand to know its effect on the causal relationships between the variables.

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