ENERGY, DEBT, AND GROWTH: TIME SERIES EVIDENCE ON CAUSALITY IN OECD EUROPEAN COUNTRIES

Mohamed Awada, Joanna Darwiche, AND *Moustapha Badran**

1. Introduction

The interactions between economic growth and debt, already addressed in the literature, appear more complex than the intuitive interpretation by political leaders aiming to stimulate growth through the leverage of debt. Regardless of the economic situation (expansion or recession), we have observed that for certain countries, the pace of GDP growth is conditioned by their energy consumption.

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*Mohamed Awada earned his Doctorate in Economic Sciences from the University of Montpellier. In his thesis, he examined the interrelationships between energy supply, public debt, and economic growth as applied to a group of OECD European countries. His research interests include macroeconomics, finance, and energy economics with a focus on European countries. He has several scientific articles published in the *Journal of Energy and Development* and other journals. His teaching expertise covers several subjects including corporate finance, financial analysis, statistics, microeconomics, macroeconomics, and financial mathematics. He is currently working as a contractual lecturer at the Faculty of Economics in Montpellier, primarily teaching a course on private economic calculus and leading econometrics tutorials.

Joanna Darwiche holds a Ph.D. in Economic Sciences from the University of Montpellier and is currently an Assistant Professor at the Faculty of Business Administration and Management at Saint Joseph University of Beirut. Her research focuses on the intersection of macroeconomics, finance, and geopolitical risks, with an emphasis on Internet globalization, exchange rates, and monetary policy in emerging markets. She also examines the impact of technological innovations, ESG factors, and energy dynamics on financial development and inflation. Joanna has been invited to present at conferences in cities such as Beirut, Montpellier, Brussels, and Istanbul. She also holds a certificate in Risk and Financial Services from the Chartered Institute for Securities & Investment. (continued)

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Shortages of raw materials and surging commodity prices, linked to the strong recovery of activity following the COVID-19 crisis, are a good illustration of this.

This aspect is predominantly explored in the literature through a demand-focused lens, emphasizing energy consumption. Furthermore, researchers typically examine the interactions between growth and energy consumption and the relationships between growth and debt separately, often neglecting the potential impacts of energy supply. Therefore, our study underscores the importance of incorporating energy supply into a comprehensive analysis that integrates all three elements: debt, growth, and energy.

This research article aims to analyze the causal links between energy supply, public debt, and economic growth for a group of European countries that are part of the OECD, a selection of major economies, and high-risk countries. The sample consists of nine European OECD countries: Belgium, Finland, Germany, Netherlands, Spain, Ireland, France, Italy, and Greece, with data collected from the OECD website. We selected these nine countries to compare major economies with high-risk countries, heavily indebted countries with less indebted ones, and northern countries with southern countries. Additionally, we aimed to compare our results with those in the literature. The availability of data on the OECD site was also a crucial factor in our selection.

Numerous studies, initiated since the beginning of the financial crisis have focused on the growth rate of GDP and levels of debt. Initially, these studies have produced varying results: the increase in public debt contributing to economic growth (Modigliani, 1961; Diamond, 1965; Saint-Paul, 1992), high levels of debt negatively affecting economic growth (Poirson et al., 2004), no significant relationship (Schclarek et al., 2004), and an inverse relationship between the variables (Kumar, 2010). Subsequently, these studies have enabled the development of a typology of countries (Gómez-Puig and Sosvilla-Rivero, 2015): bidirectional causality for France and Finland, a unidirectional causality from the percentage change in sovereign debt to economic growth for Italy, the Netherlands, and Spain, and no causal relationship concluded for Belgium, Germany, Greece, and Ireland.

In addition, the specialized studies by Giraud and Kahraman (2014) in energy economics highlight a growing interest in the role of energy in production. This raises questions about the feasibility of decoupling economic growth from energy

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Moustapha Badran holds a Doctorate in Economic Sciences from the University of Montpellier, with a research focus on corporate finance, capital structure, and financial development. Currently, he serves as an adjunct lecturer in Economics and Social Sciences at the University of Grenoble Alpes. He has several scientific articles published in the *Journal of Energy and Development* and other journals. His teaching portfolio spans a range of subjects, including theoretical and time series econometrics, as well as both macroeconomics and microeconomics.

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consumption. Moreover, it prompts an examination of whether the high dependence on energy imports in certain European countries poses challenges to their autonomous development. Could the debts accumulated since the beginning of the 21st century be more closely tied to limitations in production growth, exacerbated by these nations' energy constraints?

To address these questions, we propose an analysis of the interactions between debt, growth, and energy supply across each selected country, categorizing them based on their levels of indebtedness and energy independence. Our primary focus is on integrating energy supply dynamics into the understanding of debt and growth relationships. Through this approach, we aim to provide a comprehensive perspective on how these variables evolve over time, delineating distinct study periods for each country.

In what follows, we will proceed with a presentation of the energy-growth and debt-growth relationships discussed in the literature, followed by an overview of the macro-energy balance for each European OECD country studied. After presenting the methodology used and the data available, we will highlight the results of our study and their economic implications.

2. Literature Review

Relationship Between Energy and Growth: The relationship between energy and economic growth has been a subject of extensive research. Energy is a crucial input in the production process, influencing the output of goods and services. Several studies have examined this relationship, revealing varying results based on different methodologies and country-specific factors.

The debate surrounding the relationship between energy consumption and economic growth has given rise to two opposing views. One perspective argues that energy consumption limits growth. It has also been argued that the potential impacts of energy consumption on growth vary depending on the economic structure and growth cycle of the country in question. As economies develop, their production structure is expected to shift towards services, which are less energy-intensive activities. This viewpoint has been supported by authors such as Denison (1985), Cheng (1995), Asafu-Adjaye (2000), and Solow (2016).

The other viewpoint suggests that energy can be both the source and the engine of economic growth. Increased energy consumption is seen as a consequence of economic growth. Moreover, energy is considered a key source of economic growth because numerous consumption and production activities rely on energy as a fundamental production factor. From a physical perspective, energy consumption enhances economic productivity and industrial growth, making it essential for the development of any modern economy (Sacko, 2004).

Empirical studies thus show a unidirectional causality from total energy consumption to economic growth (applied to a group of African countries), as concluded by

Akinlo (2008) and Adebola (2011). Another unidirectional causality in the opposite direction was found in the study by Kraft and Kraft (1978) applied to the United States for the period from 1947 to 1974, and in Abaidoo's (2011) study using quarterly data over 39 years. Behname et al. (2012) conducted a study that leads to a bidirectional relationship between the two variables. Carminel (2015) concluded no relationship between energy and growth, explaining that the decoupling between energy and growth is constrained by concerns over raw material supply. For example, technologies related to energy needed to extract certain materials are subject to geopolitical constraints. The issue of raw material supply, in turn, limits the deployment of equipment necessary to improve energy intensity.

In their study of a group of countries, Erol and Yu (1987) attempted to establish the cause-and-effect relationship between energy consumption and GDP. Using Granger and Sims' causality test, they arrived at the following conclusions: there is a unidirectional causality from energy consumption to GDP for West Germany; bidirectional causality in Italy; and no causality between the two variables for France, the United Kingdom, and Canada.

Masih and Masih (1996) applied their work to six Asian countries (India, Indonesia, Malaysia, Pakistan, Philippines, and Singapore) using Johansen's methodology, vector error correction model, and variance decomposition. The differences in results can be summarized as follows: Cointegration between energy consumption and GDP was found in India, Indonesia, and Pakistan. No cointegration between the two variables was observed in Malaysia, Singapore, Pakistan, and the Philippines. Energy consumption leads GDP in India (more energy consumption leads to more growth). GDP causes energy consumption in Indonesia. There is bidirectional causality in Pakistan. These findings illustrate varying relationships between energy consumption and GDP across different Asian countries, highlighting the complexity and diversity of energy-economic interactions in regional contexts.

Chontanawat et al. (2008) evaluated the relationship between the two variables across a panel of over 100 countries, including 30 OECD member countries and 78 non-OECD member countries, to detect the relationship between energy and growth. Their findings reveal that energy consumption leads to GDP (more energy consumption leads to more growth) in 21 out of 30 OECD countries, accounting for 70%. For non-OECD countries, this relationship is found in 36 out of 78 countries, accounting for 46%. In summary, there is a more common causality between energy consumption and GDP for advanced OECD countries. From this perspective, a policy focused on limiting energy consumption would have a more pronounced negative impact on the GDP of OECD countries compared to non-member countries.

Ozturk et al. (2010) sought to test the relationship between energy and growth in four Eastern European countries: Albania, Bulgaria, Hungary, and Romania, over the period from 1980 to 2006 using the Engle-Granger model. Their conclusions indicate no causality for Albania, Bulgaria, and Romania. However, they found evidence of bidirectional causality for Hungary.

To conclude this section, various studies have explored the complex relationship between energy consumption and economic growth across different countries and regions. These investigations have revealed the links developed by Jumbe (2004), Shiu and Lam (2004), Altinay and Karagol (2005), Chen et al. (2007), Mozmuder and Marathe (2007), Squalli (2007), Apergis and Payne (2010), and Oztruk et al. (2010), and categorized into four main categories, each with significant implications for energy policy:

- *The Growth Hypothesis:* This hypothesis asserts that there is a unidirectional relationship between energy consumption and economic growth. It argues that energy consumption plays a pivotal 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 alongside traditional factors like capital and labor. Under these conditions, the implementation of energy policy influences the level of production, as indicated by Yu and Choi (1985), Tsani (2010), Belke et al. (2011), and Destek (2016).
- *The Conservation Hypothesis:* Economic growth leads to an increase in energy consumption. This hypothesis suggests 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 supported. Indeed, Paul and Bhattacharya (2004), Hatemi et al. (2005), and Gelo (2009) argue that energy-saving policies can be implemented with little or no negative effects on economic growth.
- *The Neutrality Hypothesis:* It implies that there is no cause-and-effect relationship between energy consumption and economic growth. These two variables are not correlated. In other words, any increase or decrease in energy consumption has no effect on economic growth. This means that neither energy-saving policies nor intensive energy policies influence the level of wealth creation in an economy, as explained by Jobert and Karanfil (2007).
- *The Feedback Hypothesis:* It asserts that there is bidirectional causality between energy and economic growth. This means that energy and economic policies should be implemented jointly. In this case, energy consumption policies should be developed to avoid any negative impact of energy on growth. Studies applied to one or groups of countries (e.g., Greece, G7, OECD countries) support this view, according to Hondroyiannis (2004), Lee et al. (2008), Mutascu (2016), and Dos Santos Gaspar et al. (2017).

The variability in how energy influences economic growth necessitates tailored policy approaches that account for local economic conditions, energy infrastructure, and environmental considerations to foster sustainable development. Similarly, the relationship between debt and economic growth is complex, with debt serving as both a tool for financing growth and a potential risk to economic stability. Effective management of public debt requires strategies that balance short-term economic benefits with long-term fiscal sustainability.

Relationship Between Debt and Growth: The empirical literature on this relationship between debt and growth not only presents ambiguous results but also primarily focuses on the possible impact of high debt levels on economic growth, often overlooking the potential reverse causality from growth to debt (with rare exceptions: Ferreira, 2009; Puente-Ajovín and Sanso-Navarro, 2015).

However, Bell et al. (2015) find theoretical evidence suggesting that public debt is likely to accumulate when growth is low. In this regard, with low growth implying limited public revenues, governments may be compelled to increase their level of indebtedness to sustain the welfare state, stimulate short-term demand, and foster long-term growth, according to Feldstein (2014).

Theoretically, neoclassical and endogenous growth models, such as those by Modigliani (1961), Diamond (1965), and Aizenman et al. (2007), suggest that high levels of public debt would undoubtedly reduce the rate of economic growth. Other channels through which public debt may negatively affect long-term growth include the hypothesis of over-indebtedness (Krugman, 1988; Roubini and Sachs, 1989), the liquidity constraint hypothesis (Moss and Chiang, 2003), the crowding-out hypothesis (Hansen, 2004), and uncertainty effects (Codogno et al., 2003; Cochrane, 2011). Another channel through which high indebtedness can have a negative impact on growth is through long-term interest rates (Elmendorf and Mankiw, 1999; Tanzi and Chalk, 2000).

Checherita and Rother (2012) analyzed the average impact of public debt on per capita GDP growth in 12 Eurozone countries over a period of about 40 years starting from 1970. They concluded that there is a non-linear effect of debt on growth, with a turning point beyond which the public debt-to-GDP ratio has a negative impact on long-term growth, estimated to be around 90-100% of GDP. Panizza and Presbitero (2014) studied the causal effect of public debt on economic growth in a sample of OECD countries. Their findings align with existing literature, demonstrating a negative correlation between the two variables.

Mencinger et al. (2014) empirically studied the relationship between public debt-to-GDP ratios and GDP growth across a panel of 25 EU countries. They divided the countries into old and new member states and used panel estimation in a generalized economic growth model augmented with a debt variable. Their findings indicated a statistically significant non-linear impact of public debt ratios on annual per capita GDP growth rates. They identified a turning point in the debt-to-GDP ratio where the positive effect of debt accumulation shifts to a negative effect, approximately between 80% and 94% for old member states and between 53% and 54% for new member states. This research contributed to understanding the implications of high public debt on economic activity within the EU.

Finally, some effects associated with financial liberalization, such as increased bank risk-taking and significant accumulation of external debt, can make a country vulnerable to economic shocks that often lead to severe recessions (Eichengreen and Leblang, 2003; Nyambuu and Bernard, 2015). Given the theoretical predictions highlighted above, it is somewhat surprising that the conclusion by Reinhart and Rogoff (2010), stating that countries' debt should not exceed 90% of GDP, beyond which GDP growth rates decrease significantly, sparked such controversy. Others have strongly criticized this conclusion, noting that during the period 1946-2009, countries with a public debt-to-GDP ratio exceeding 90% actually showed an average annual real GDP growth of 2.2%, not −0.1%.

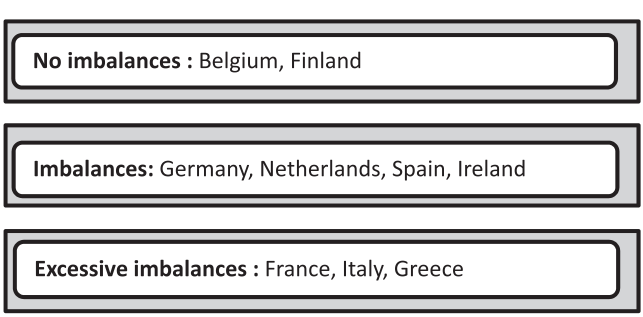
All the previous research highlights the interest in determining the potential short-term and long-term relationships between energy, debt, and growth, this will be addressed in the next section by presenting a macro-energy balance of the sample consisting of nine European countries. The aim is to provide a comprehensive overview of the strengths and challenges faced within the European region.

Macro-Energy Balance of the Nine European Countries: We present in this section the macro-energetic state, which allows us to explain through the literature the energy situation (energy supply) and macroeconomic situation (public debt and economic growth) of each selected European OECD country in order to compare it with the empirical part.

The sample of nine European countries is divided into three categories based on their level of debt (Benassy, 2017) as outlined in Figure 1. The first category includes Belgium and Finland, countries that do not exhibit any imbalances. The second category consists of countries with imbalances: Germany, where public investment is insufficient; the Netherlands, with private debt; and Spain and Ireland, with both private and public debt. The three remaining countries form the third category, which is characterized by excessive imbalances: France, characterized by public debt; Italy, with unemployment and a lack of competitiveness; and Greece, marked by its fragility following the financial crisis and the sovereign debt crisis.

Belgium: The supply of primary energy is considerable thanks to imports (96% of energy needs in 2030), divided between oil (the most important energy source,

Figure 1
CLASSIFICATION OF THE NINE EUROPEAN COUNTRIES BY DEBT LEVEL



up to 40% of demand) and gas (Marbraix and Van Ypersele de Strihou, 2004). Goals have also been set to reduce fossil fuel consumption so that it will represent 4% of final demand in favor of gas and electricity (Gusbin and Hoornaert, 2004).

The relationship between debt and growth has been influenced by significant temporal events. Since 1969-1970, there has been a period marked by inflation, deteriorating productivity, and unemployment. The two oil shocks of 1973 and 1979 led to a 70% increase in the price of oil, causing growth to stall. Keynesian reforms resulted in a widened budget deficit, bringing the debt-to-GDP ratio to 106% in 1983. The crisis persisted through the 1980s, leading to increased indebtedness and resulting in stagflation. Despite an easing of problems after 2000, the financial crisis pushed the ratio back up to 100% in 2010 and to 105.2% today. Despite the negative impact of debt on growth, a high level of debt does not pose an obstacle to the country's short-term growth.

Finland: Finland's energy policy is characterized by the diversification of supply despite its dependence on foreign countries. International interest in Finnish energy policy has been very strong for several reasons. Firstly, electricity markets were liberalized in the early 2000s. Secondly, the construction of a nuclear power plant was authorized by parliament in 2002. Additionally, Finland is the only country in the world where the permanent disposal of spent nuclear fuel in bedrock has been approved at both national and local levels. Finally, the use of renewable energy is twice as high, with its total share being among the highest in the EU (28.5%) (Ruostetsaari, 2009).

The Finnish economy has faced frequent difficulties since the onset of the global crisis: in 2016, GDP fell to 4.5% below the level reached in 2008, and the debt-to-GDP ratio nearly doubled between 2008 and 2016, reaching 64% of GDP (75.23% in 2023). Three types of reasoning have been proposed to explain this unfavorable outcome. Firstly, Finland was hit by the 2008 crisis, which was beyond the control of political authorities. Secondly, macroeconomic policy was unable to mitigate the impact. Finally, the economy lacked flexibility and resilience in the face of shocks. Although the national economy suffered from weak growth, it has now returned to growth thanks to an improved external environment (including the absorption of shocks) and sound policies supported by certain underlying strengths (Vihriälä, 2017).

Germany: Germany places great importance on environmental issues and was one of the promoters of the Kyoto Protocol (Sievers et al., 2019). It heavily depends on fossil fuel imports, with an energy dependency rate of 62% in 2006 (Energiebilanzen, 2018). As the largest importer of fossil fuels in Europe and the biggest CO_2 emissions producer, Germany faces high energy prices compared to the European average. To reduce CO_2 emissions and limit dependency, a strategy of reducing energy consumption is necessary (Fischer, 2009). The future of energy supply is uncertain, whether through importing gas from Russia or the massive use of fossil fuels (Deshaies, 2007). Although perceived as costly, the energy transition could be advantageous due to fossil fuel scarcity and reduced imports through renewable energy sources (Linkohr, 2013). Despite the discovery of new deposits, the end of the oil era will not be due to a lack of oil, just as the Stone Age did not end due to a lack of stones (Autret, 2007).

On the macroeconomic front, Germany was the most affected country by the financial crisis in Europe due to its strong dependence on trade, but its responsiveness allowed it to overcome the crisis (Storm and Naastepad, 2015). There is substantial evidence of the short- and long-term link between debt and growth in Germany, based on estimates from dynamic error correction models. The results suggest a significantly negative relationship between regional public debt and per capita GDP in the long term (Mitze and Matz, 2015). A restraint on debt will be necessary to invigorate a European debate on the feasibility of consolidation.

Netherlands: Although the Netherlands is well-equipped with natural resources, it is also dependent on foreign supply. Starting in 1850, the consumption of imported coal increased rapidly, causing concern among politicians. In 1901, state mines were established to exploit domestic coal, and its production gradually increased. During the interwar period, the Netherlands became almost self-sufficient in coal, leading to a transition towards dependence on oil. In 1959, natural gas was discovered, and the government partnered with state mines for its exploitation. The rapid introduction of natural gas reduced the role of coal, but dependence on imported oil remained. The oil crisis triggered a reorientation of energy policy, emphasizing diversification of both resources and supplier countries. The Dutch government has been heavily involved in previous energy transitions and will also play a significant role in the transition to renewable energy (Hölsgens, 2019).

Regarding the relationship between debt and growth, a unidirectional relationship, applying the Granger causality test, is inferred from sovereign debt to economic growth. Furthermore, variations in public debt also began to have a negative effect on growth starting in 2009, when the debt-to-GDP ratio reached 56% (Gómez-Puig and Sosvilla-Rivero, 2015). More recently, the debt-to-GDP ratio remains at 46.50% in 2023.

Spain: Spain is going through a period of growth with a focus on energy supply. Historically, in the 1970s, it experienced high inflation and low economic growth, unlike the last two decades, which saw a 62% increase in GDP between 1990 and 2010. Its energy model is characterized by growing energy demand, CO_2 emissions, and heavy dependence on fossil fuels (Girard et al., 2016). Previous studies have already confirmed the impact of oil shocks on GDP, generally reflecting the relationship between energy and macroeconomics, which has been declining since the 1970s-1980s, primarily due to the reduced share of oil in the economy.

The sovereign debt crisis in Europe initially affected Iceland, Ireland, and Greece before spreading to Spain. Spain demonstrated its ability to cope, though it faced significant budget deficits between 2008 and 2009 and since 2012. The negative relationship between debt and GDP led to a debt-to-GDP ratio increasing from

40.2% in 2008 to 107.7% currently. Gruppe and Lange (2014) observed a convergence with the German market, noting a structural break starting from early 2009. However, Granger causality tests applied over time and space between 1980 and 2013 (Gómez-Puig and Sosvilla-Rivero, 2015) suggest evidence of a feedback loop between low growth and high debt levels in Spain following the break. Therefore, it is essential to reduce public debt while considering the short-term negative effects of budget adjustments on growth prospects (Jaramillo and Cottarelli, 2012).

Ireland: In the current period of heightened awareness regarding climate change and the foreseeable scarcity of fossil fuels, Ireland has developed a new approach for its energy future. In this context, Ireland is heavily dependent on imports of oil and gas, which continue to increase to meet demand. Irish policy is guided by multi-year strategic plans that set objectives and modalities. Priority is given to ensuring supply security at reasonable prices: €8.5 billion was allocated for the period 2007-2013 for renovating existing energy infrastructure and businesses, and to a lesser extent, supporting the development of renewable energy sources. Additionally, integrating renewable energy sources into the electricity grid and ensuring supply stability have been the focus of research by Saintherant et al. (2008).

During the Celtic Tiger era from around 1994/1995 to the global financial crisis of 2007/2008, Ireland experienced a significant economic and cultural transformation, reaching its peak in development (Whelan, 2014). In recent years, Ireland has seen one of the most remarkable economic recoveries among Eurozone countries. By 2007, Ireland was hailed as Europe's top-performing economy with sustained high growth, low unemployment, and budget surpluses. However, the subsequent crash—marked by a property market collapse, surging unemployment, and a severe banking crisis—proved extremely challenging. Ireland entered an EU and IMF adjustment program in 2010 and is now poised to exit, though economic conditions remain tough with high unemployment. Despite this, Ireland is often cited as a model for other countries facing economic difficulties (Murphy, 2016), with a debt-to-GDP ratio of 43.70% in 2023.

France: On the European level, the goal is to achieve a unified energy market by removing regulatory barriers, which also influences French policy towards boosting exports (Andriosopoulos and Silvestre, 2017). During the 1970s, France, highly dependent on energy, was severely affected by two oil crises. Ensuring energy supply security is crucial for assessing its energy structure. Primary energy production peaked in 2015 but has since declined to 132 million tonnes of oil equivalent (Mtep) in 2017, primarily due to reduced nuclear and hydroelectric output. Fossil fuel production is minimal (none for coal and natural gas, and 1 Mtep for crude oil). Fossil fuel imports, particularly oil and coal, have risen by 3.3% due to increased demand. Despite these challenges, electricity exports have grown steadily since 1980. As of 2017, France's energy independence rate was 53% (currently 55%), decreasing by 0.5% from 2016 due to reduced nuclear power generation (Baudry et al., 2019).

Among the top five economies in the Eurozone (Spain, Italy, Germany, France, and the Netherlands), only French debt has increased proportionally to GDP since the 2008 financial crisis (Égert et al., 2011). Although limited, several studies converge on highlighting that a high level of public debt can restrain long-term growth. Specifically, public debt exceeding 90% of GDP is associated with a GDP growth reduction of 1 to 3 percentage points on average for developed countries, and 0.5 percentage points for France (Reinhart and Rogoff, 2010). Furthermore, a 10-percentage-point increase in the debt-to-GDP ratio decreases annual growth by 0.15 percentage points (Woo and Kumar, 2015). Lastly, there is an impact on potential growth of at least 1 percentage point above a debt level of 80% to 120% of GDP (Checherita and Rother, 2010). In France, public debt has quickly approached the 90% threshold (98.1% in 2019 and 110.6% in 2023), potentially posing a threat to long-term growth.

Italy: On the energy front, Italy's strong dependence on imports, primarily oriented towards hydrocarbons, may intensify over time as these resources become less available. The high demand for petroleum products, coupled with low European production, leads to an increasing need for foreign sourcing. Therefore, achieving a correlation between economic growth and sustainable development will be necessary to meet greenhouse gas reduction targets (Schifano and Moriconi, 2009).

According to the OFCE (Antonin et al., 2019), Italy faces two major challenges: negative growth and a heavy burden of public debt relative to GDP. The evolution of the debt-to-GDP ratio since 1960 can be divided into four phases: moderate debt growth (1960-1980), inflated debt due to increased deficits and interest (1980-1994), consolidated debt with reduced financial charges (1994-2008), and a disruption in stability due to recession (2008-2019). To address current issues, the only viable solution is to improve real GDP growth, which has been negative especially during the periods of 2008-2009 and 2012-2013. Italy needs more support from Europe to enhance its growth rate and subsequently reduce its debt; abandoning the euro would lead to debt catastrophes, necessitating cooperation with other countries to ensure successful growth recovery policies.

Greece: During the rapid growth period from 1960 to 1973, Greece experienced annual increases of 12.6% in final energy consumption and robust economic growth averaging 7.7%, alongside a 12.3% rise in total energy consumption. However, by 1980, annual growth in final energy dropped to 4.3%, coinciding with Greece's economic growth slowing to an average of 1.6% annually (Hondroyiannis et al., 2002). Despite the 1970s oil shocks, Greece improved its energy intensity. Dependent heavily on energy imports, particularly oil, which constituted 79% of expenditures in 1996, Greece aimed to reduce economic disparities in the early 1990s, enhancing competitiveness by reducing inflation from 15.9% in 1992 to 3.7% in 1998 (Ministry of Environment, Energy and Climate). However, by the end of 2008, CO_2 emissions had risen 26% above 1990 levels, reflecting energy efficiency challenges (Hatzigeorgiou et al., 2011). Greece's energy issues stem from poor sectoral performance and limited alternative sources, necessitating a strategy emphasizing the development of substitute energy sources to reduce reliance on imported oil. Key objectives of Greek energy policy include advancing alternative energy sources and international collaboration on energy management projects (Donatos and Mergos, 1989).

Extensive public spending in Greece has significantly increased government debt, a trend highlighted in studies by Schclarek et al. (2004), Adam and Bevan (2005), and others, which reveal a long-term negative correlation between public debt and economic growth. Financial crises have exacerbated this relationship, leading to reduced economic growth rates and a surge in debt levels. Furthermore, research, including findings from Pattillo et al. (2002), underscores a persistent negative association between external debt and economic growth. Spilioti and Vamvoukas (2015) conducted further analysis on Greece, incorporating variables such as fiscal policy indicators, economic openness, external competitiveness, demographic characteristics, and indicators of the country's capacity for investment and short-term financing. Their findings highlight key determinants of GDP growth rate, including debt levels, GDP per capita, gross national savings, total imports and exports, trade dynamics, unemployment, and population growth rate (Smyth and Hsing, 1995; Nguyen et al., 2003; Reinhart and Rogoff, 2010).

After presenting the theoretical macro-energy state for each of the nine OECD European countries, we will analyze the possible links between three variables: energy supply, public debt, and economic growth. To ensure comparability with existing literature, we will conduct a country-specific analysis, grouping them into several categories. While inter-country analysis is certainly of interest, it will be the subject of future research, as it requires causality tests involving numerous combinations to determine whether the dynamics of one variable in a country cause those in another country.

3. Data and Methodology

Modeling VAR and Causality Tests: To highlight the relationships between the variables, we will construct VAR models to study Granger causality between stationary variables (or variables made stationary in the case of non-stationary or differenced processes). VAR(P) modeling is based on a system of lagged equations of order P, where each variable is both explanatory and explained. The minimization of the Akaike criterion also determines the optimal lag order P. Assuming two stationary time series x_t and y_t, the VAR(P) model is therefore written as follows:

$$x_t = \alpha_1 + \sum_{j=1}^{P} \beta_{1,j} x_{t-j} + \sum_{j=1}^{P} \gamma_{1,j} y_{t-j} + \varepsilon_{1,t} \quad (1)$$

$$y_t = \alpha_2 + \sum_{j=1}^{P} \beta_{2,j} x_{t-j} + \sum_{j=1}^{P} \gamma_{2,j} y_{t-j} + \varepsilon_{2,t} \tag{2}$$

(α_i, $\beta_{i,j}$, $\gamma_{i,j}$) represent the parameters of the VAR(P) model, and $\varepsilon_{i,t}$ represent the innovations following an independent and identically distributed process (0, σ_ε^2) with i = 1, 2 and j = 1 … .P.

From estimating this model, it is possible to analyze the contemporaneous impact on x_t and y_t of a shock at time t on the innovations $\varepsilon_{i,t}$ and its propagation, meaning its effects on the variables in period h, x_{t+h} and y_{t+h} with h=1 … H. This allows us to obtain the impulse response functions of x_t and y_t following a shock on $\varepsilon_{i,t}$ for all i = 1, 2.

Since we have the series response for period h, it is possible to calculate the forecast error variance for each variable and attribute the proportions due to shocks on $\varepsilon_{i,t}$. This allows us to obtain variance decomposition tables (Hamilton, 1994).

Granger (1969-1988) defines causality as the ability of y_t to predict x_t, meaning if the historical information of y_t is included in x_t. Therefore, a VAR model allows testing the hypothesis that y_t does not cause x_t by testing restrictions on its parameters, specifically $\gamma_{1,1} = \gamma_{1,2} = \gamma_{1,P} = 0$ (using tests such as Fisher, Wald, or Likelihood-Ratio tests through a likelihood ratio). The reverse relationship — whether x_t does not cause y_t — is examined by testing if $\beta_{1,1} = \beta_{1,2} = \beta_{1,P} = 0$.

When variables do not share the same characteristics (either all stationary or cointegrated of the same order), the traditional Granger causality approach cannot be applied. Toda and Yamamoto (1995) proposed a method that overcomes this limitation by allowing for testing causality (in the Granger sense) between variables of different natures. Their methodology builds upon a standard VAR(P) model. Once the order P is determined, they suggest estimating an augmented VAR model (VAR(P+m)), where m is the maximum order of integration identified for any variable (in our case, m is equal to 1). The causality test is then conducted using a Wald test on the parameters of the augmented VAR model.

Assuming two stationary time series x_t and y_t, the VAR(P+1) model is written as follows:

$$x_t = \alpha_1 + \sum_{j=1}^{P+1} \beta_{1,j} x_{t-j} + \sum_{j=1}^{P+1} \gamma_{1,j} y_{t-j} + \varepsilon_{1,t} \tag{3}$$

$$y_t = \alpha_2 + \sum_{j=1}^{P+1} \beta_{2,j} x_{t-j} + \sum_{j=1}^{P+1} \gamma_{2,j} y_{t-j} + \varepsilon_{2,t} \tag{4}$$

(α_i, $\beta_{i,j}$, $\gamma_{i,j}$) represent the parameters of the VAR(P+1) model, and $\varepsilon_{i,t}$ represent the innovations following an independent and identically distributed process process (0, σ_ε^2) with i = 1, 2 and j = 1 … .P+1.

Stationarity Tests of the Selected Variables: Stationarity tests of variables are crucial to ensure that the time series used in VAR analysis are suitable. Several commonly used tests include the Augmented Dickey-Fuller (ADF) test. These tests assess whether a time series has unit roots, which would indicate non-stationarity. Specifically, the ADF test is often preferred because it can detect the presence of unit roots even in the presence of serial correlation. To conduct these tests, the null hypothesis is specified that the series has a unit root (is non-stationary). If the test results reject this null hypothesis, it suggests that the series is stationary. Once all series are stationary or made stationary through differencing, they can be appropriately used in a VAR model to analyze relationships between them.

The data were extracted from OECD Economic Outlook No. 115-May 2024 (primary energy supply, government gross financial commitments, and gross domestic product in volume terms at market prices). To extend the series, we also used OECD Economic Outlook No. 73-June 2003 for all selected countries, in order to obtain the broadest possible observations (data calibration between two sources of data).

We present three variables. Firstly, primary energy supply represents the sum of energy production and imports, adjusted for exports, international bunkers, and stock changes. The calculation method by the International Energy Agency (IEA) is based on the calorific value of energy products and a common unit of account, the tone of oil equivalent (toe), equal to 107 kilocalories (41.868 gigajoules) (Primary energy supply). Secondly, public debt, which is the gross debt of general government, is a key indicator of public finance sustainability. Debt includes cash and deposits, securities other than shares, loans, insurance, pensions, and standardized guarantee schemes and other accounts payable. Changes in public debt over time primarily reflect the impact of past government deficits. This variable is expressed in euros (General government gross financial liabilities). Finally, economic growth, indicated by annual variations in gross domestic product (GDP), is the standard measure of value added from the production of goods and services in a country over a specific period. Real GDP, expressed in euros, refers to GDP in constant prices and reflects the volume level of GDP (Gross domestic product, volume, market prices). We have a sample of nine European countries (Table 1). The observation period varies for different countries.

Before analyzing the potential relationships between these three variables, we will examine whether they are stationary or not. Preliminary investigation into the stationarity of variables is essential before any estimation. For this purpose, we can use the Dickey-Fuller Simple or Augmented test (Dickey and Fuller, 1979-1981). The Dickey-Fuller test is preferred in the case of homoscedastic variances. The Dickey-Fuller test is based on several models that help identify the nature of

Table 1
REPRESENTATION OF THE NUMBER OF OBSERVATIONS PER STUDIED EUROPEAN COUNTRY

Country	**Period**	**Number of observations**
Belgium	1970-2023	54
Finland	1970-2023	54
Germany	1970-2023	54
Netherlands	1970-2023	54
Spain	1970-2023	54
Ireland	1970-2023	54
France	1970-2023	54
Italy	1970-2023	54
Greece	1970-2023	54

non-stationarity depending on the structure of the process generating the time series x_t, whether it has a stochastic or deterministic trend (TS or DS with/without a constant).

We follow the testing procedure developed by Ertur (1991-1998) and rely on minimizing the Akaike Information Criterion (AIC) to select the optimal lag P. This procedure for a simple DF test starts with estimating the model with trend and constant:

$$x_t = \emptyset_1 . x_{t-1} + \varepsilon_t + bt + \mathrm{c} \tag{5}$$

$$\Delta x_t = (\emptyset_1 - 1) . x_{t-1} + \varepsilon_t + bt + \mathrm{c} = \rho . x_{t-1} + \epsilon_t + bt + \mathrm{c} \tag{6}$$

With t as time, $\emptyset_1$ as the coefficient associated with lag 1, $\rho = (\emptyset_1 - 1)$ and ϵ_t representing innovations following an i.i.d. process (0, σ_ε^2).

The null hypothesis of non-stationarity for the process x_t implies that $\emptyset_1 = 1$, or equivalently $\rho = 0$. Under this hypothesis, the process x_t is autocorrelated at lag 1, known as a random walk (DS process), meaning the differenced series Δx_t is a random process. Conversely, under the alternative hypothesis, $|\emptyset_1| < 1$, the process x_t is a stationary AR(1) process.

The Augmented Dickey-Fuller test evaluates the nullity of $\emptyset_1$ while considering the autocorrelation of the series. A lag polynomial $\theta(B)$ applied to the differenced series Δx_t adjusts the original test models to account for autocorrelation.

Thus, the complete model (including a trend and a constant) is written as follows:

$$\theta(B)(1 - \emptyset_1 B)x_t = c + \ + b.t + \varepsilon_t \tag{7}$$

Table 2
STATIONARITY TEST RESULTS

Country	Energy supply (ESU)	Public debt (PDE)	Economic growth (EGR)
Belgium	Stationary	Non-Stationary (DS)	Stationary
Finland	Stationary	Stationary	Stationary
Germany	Non-Stationary (TS)	Non-Stationary (TS)	Non-Stationary (TS)
Netherlands	Non-Stationary (TS)	Non-Stationary (TS)	Non-Stationary (TS)
Spain	Stationary	Stationary	Non-Stationary (DS)
Ireland	Stationary	Stationary	Stationary
France	Non-Stationary (TS)	Non-Stationary (TS)	Non-Stationary (TS)
Italy	Non-Stationary (TS)	Non-Stationary (TS)	Non-Stationary (TS)
Greece	Non-Stationary (TS)	Non-Stationary (TS)	Non-Stationary (TS)

With t as time, $Ø_1$ the coefficient associated with the first lag; B as the lag operator; and ε_t the innovations following an i.i.d. process $(0, \sigma_\varepsilon^2)$. $\theta(B)$ is the lag operator polynomial of degree $(p-1)$.

Therefore, the null hypothesis is still $Ø_1 = 1$ or $\rho = (Ø_1 - 1).(1 - \theta_1 - \theta_2 - \theta_{p\text{-}1}) = 0$ and the alternative hypothesis of stationarity remains $|Ø_1| < 1$.

The nullity of ρ represents the null hypothesis of the test, indicating the presence of a unit root. However, it is appropriate to test the joint nullity of ρ along with the parameters c and b, which represent the constant and the slope of the trend, respectively. Depending on the result obtained, it is necessary to estimate a model without the trend and to reiterate the joint nullity tests of the parameters. Table 2 provides an overview of the stationarity test results.

4. *Results and Discussion*

Henceforth, we refer to the following acronyms to characterize our variables: energy supply, public debt, and economic growth.

- PDE corresponds to the debt variable. This is stationary either by nature or through a "stationarization" operation of TS processes.
- ESU corresponds to the primary energy supply variable. This is stationary either by nature or through a "stationarization" operation of TS processes.
- EGR corresponds to the economic growth variable. This is stationary either by nature or through a "stationarization" operation of TS processes.

We will present the empirical results defined by the results of Granger causality tests, variance decomposition, and impulse response functions. For the analysis of these, we interpret the results following a positive shock.

Belgium: We note from the Granger test a unidirectional causality relationship at the 5% threshold from EGR to PDE. Variance decomposition shows that 88% of the forecast error variance in EGR is due to its own shocks, and 12% to those of PDE. Regarding debt, variance decomposition shows that 68% of the forecast error variance in its growth is due to its own shocks, and 32% to those of EGR. However, the Granger test does not indicate causality in this direction at the 5% threshold, but at the 10% threshold, the response effect of debt is significant, implying bidirectional causality. Impulse response functions show that PDE reacts immediately and negatively to a shock on EGR, but the effect becomes positive after period 2 before tapering off. In the case of a shock on PDE, EGR does not react immediately but shows a maximum negative effect after 2 years. At the 10% threshold, we note a bidirectional causality relationship between EGR and ESU. The response of the latter to a shock on EGR is immediate and positive, but the effect becomes negative in period 2 before canceling out. Conversely, EGR does not react immediately to a shock on ESU, but a positive effect is noted after 2 years (see Appendix 1).

Finland: We do not observe a causality relationship between ESU and the other variables. The results from the Granger causality tests indicate EGR causes PDE. The variance decomposition table confirms this result, showing that 64% of the forecast error variance in PDE is due to shocks in EGR, with only 36% attributable to its own shocks (see Appendix 2). Therefore, a shock on EGR leads to a negative response in PDE, with a maximum effect seen at 2 years before tapering off after periods of 4-5 years.

Germany: The results from the bivariate Granger causality tests indicate that there is no causality relationship between PDE and ESU. Only EGR, as per Granger causality, influences PDE. This finding suggests a unidirectional causal relationship between these two variables, primarily driven by EGR. The variance decomposition analysis shows that 73% of the forecast error variance in PDE is due to its own shocks, while 27% is attributable to EGR (see Appendix 3). Examining the impulse response functions of the stationary VAR, we observe an immediate negative reaction of PDE following a shock to EGR. The maximum effect is seen at period 2, which is 2 years after the shock in PDE, and diminishes after periods of 4-5 years.

Netherlands: We observe a unilateral causality relationship from PDE to EGR at the 5% significance level. According to the variance decomposition table, 63% of the forecast error variance in EGR is due to its own shocks, while 37% is attributed to shocks in PDE, which has an instantaneous negative impulse response (see Appendix 4). The maximum effect of the shock is reached at period 2 and gradually diminishes until periods 5-6. Furthermore, we notice another causality relationship from EGR to ESU at the 10% significance level. The response of ESU is immediate and positive, lasting until periods 5-6.

Spain: The results of the Granger causality tests indicate three causal relationships at the 5% significance level. First, PDE causes EGR. Additionally, there is a bidirectional relationship between ESU and EGR. According to the variance decomposition tables, 50% of the forecast error variance in EGR is due to its own shocks, and 50% is attributed to shocks in ESU (see Appendix 5). The response is not instantaneous but starts positively at period 2, peaks at period 3, and then diminishes. Regarding the feedback effect (from EGR to ESU), we observe that 86% of the forecast error variance in ESU is due to its own shocks, while 14% is due to shocks in EGR. A positive response in ESU begins in period 1 (not instantaneous), continues until period 2, and then turns negative from period 3 onward. Similarly, the variance decomposition shows that 58% of the forecast error variance in EGR is due to its own shocks, and 42% is due to shocks in PDE. Analyzing the impulse response functions, a shock in PDE to EGR does not result in an immediate reaction but rather a response starting from period 2 with a positive and sustained effect.

Ireland: Based on the Granger causality test results, it is evident that ESU is influenced by PDE. Despite the p-value being above 5%, EGR also causes ESU. The variance decompositions (see Appendix 6) reveal that 76% of the forecast error variance in ESU is due to its own shocks, and 24% is due to shocks in PDE. Additionally, the variance of the forecast error in ESU is attributed to 79% of its own shocks and 21% to EGR. Examining the impulse response functions, a shock in PDE leads to a negative response in ESU) over 2-4 years before slowly dissipating. This same shock also triggers an instantaneous negative response in EGR over a period of 3 years. Finally, a shock in EGR positively and instantaneously affects ESU up to period 4. Hence, it can be inferred that the effect of EGR on ESU results from the significant impact of PDE on EGR (cross-effect). The faster PDE accelerates, the weaker EGR and ESU becomes.

France: Based on the tests, at the 5% significance level, PDE causes EGR. The variance decomposition table indicates that 70% of the forecast error variance in EGR is due to its own shocks, and 30% is due to shocks in PDE (see Appendix 7). Impulse response functions reveal that EGR responds immediately but negatively to a shock in PDE, with effects tapering off over a period of 4-5 years. The bidirectional nature of the relationship, meaning causality from EGR to PDE, only appears at the 10% significance level. However, the response is not instantaneous, as we observe a negative and maximal reaction 2 years later. Also at the 10% significance level, we note a unilateral causal relationship from ESU to PDE.

Italy: For Italy, Granger causality tests reveal a unidirectional relationship from the increase in PDE to ESU. According to the variance decomposition table, 72% of the forecast error variance of ESU is attributable to its own shocks, while 28% is due to shocks from PDE (See Appendix 8). Impulse response functions indicate that ESU does not react immediately, but its response peaks negatively after two years.

Greece: The Granger causality tests indicate that EGR affects both PDE and ESU. According to the variance decomposition table, 60% of the forecast error variance of ESU is due to its own shocks, while 40% is attributable to shocks from EGR (See Appendix 9). There is an immediate positive response of ESU to this shock, reaching its peak effect at 2 years before attenuating around period 5. The variance decomposition table indicates that 90% of the forecast error variance of PDE is due to its own shocks, and 10% to EGR, with a diffusion that attenuates over 5 years. There is an immediate positive response at period 1, but it turns negative by period 2.

Our country-specific findings highlight a new dimension for categorizing countries, considering both debt-growth classification and energy supply classification.

Regarding the relationship between debt and growth, countries can be divided into two groups (See Appendix 10). Firstly, group 1 – lowly indebted: PDE does not exceed 100% of EGR for northern countries: in 2023, Germany was at 63.60%, Ireland at 43.70%, Finland at 75.80%, and the Netherlands at 46.50%. Among northern European countries, only Belgium has a debt exceeding 100% at 105.2%. This group can be divided into two parts. On one side, Germany and Finland are characterized by a unidirectional causality relationship from EGR to PDE (a positive shock in EGR leads to a negative response in PDE). On the other side, Ireland and the Netherlands are characterized by a unidirectional causality relationship from PDE to EGR.

Secondly, group 2 – highly indebted: In 2023, PDE exceeded 100% of EGR for Southern European countries as follows: Spain was at 107.70%, France at 110.60%, Greece at 161.90%, and Italy at 137.30%. This group can be divided into 2 subgroups. On one hand, France and Spain mainly exhibit a 5% causal relationship from debt to economic growth. On the other hand, Belgium and Greece are characterized by a causal relationship from economic growth to debt (debt reacts negatively to a shock in growth). Italy alone among Southern countries shows no causal relationship between these two variables (debt and economic growth).

In terms of energy supply, countries can be grouped accordingly (a different distribution from the literature). One group (A) consists of countries with an energy dependency rate exceeding 50% and at least one causal relationship (at 5%), either to or from energy supply: Spain, Italy, Greece, and Ireland. These countries are part of the GIIPS, the most affected countries after the global financial crisis. The other group (B) consists of energetically independent countries with no significant causal relationship (at 5%): Germany, Finland, the Netherlands, and France. Belgium is an exception as it shows no significant causal relationship but has a bidirectional relationship at 10% and is subsequently dependent on energy imports. Therefore, a country with an energy dependency rate below 50% shows no causality to or from ESU, with equal proportions of production and importation. Conversely, a country with a high dependency rate shows at least one significant causal relationship between ESU and one of the other variables (PDE or EGR), with imports comprising a very high percentage compared to production.

Overall, countries in the North have a PDE to EGR ratio below 100% and a low energy dependence rate, and vice versa. Resolving the debt issues in troubled countries is necessary to encourage them to produce and import more energy to achieve growth objectives. These findings are derived from Granger causality tests (See Appendix 10).

5. *Conclusion*

This study examines the relationships between energy supply, public debt, and economic growth in nine OECD European countries. Using VAR models, as well as Granger and Toda-Yamamoto causality tests, we find that economic dynamics differ significantly between northern and southern European nations.

In northern countries like Germany and Finland, economic growth influences debt levels, indicating growth's role in debt management. Conversely, in Ireland and the Netherlands, debt levels impact economic growth. In southern Europe, high debt negatively affects growth in countries like Spain and France, while Greece and Belgium show the reverse causality.

Energy dependency is critical, with countries like Spain, Italy, Greece, and Ireland showing significant causal links between energy supply and economic variables due to high import reliance. In contrast, energy-independent nations like Germany, Finland, and the Netherlands exhibit more stable interactions.

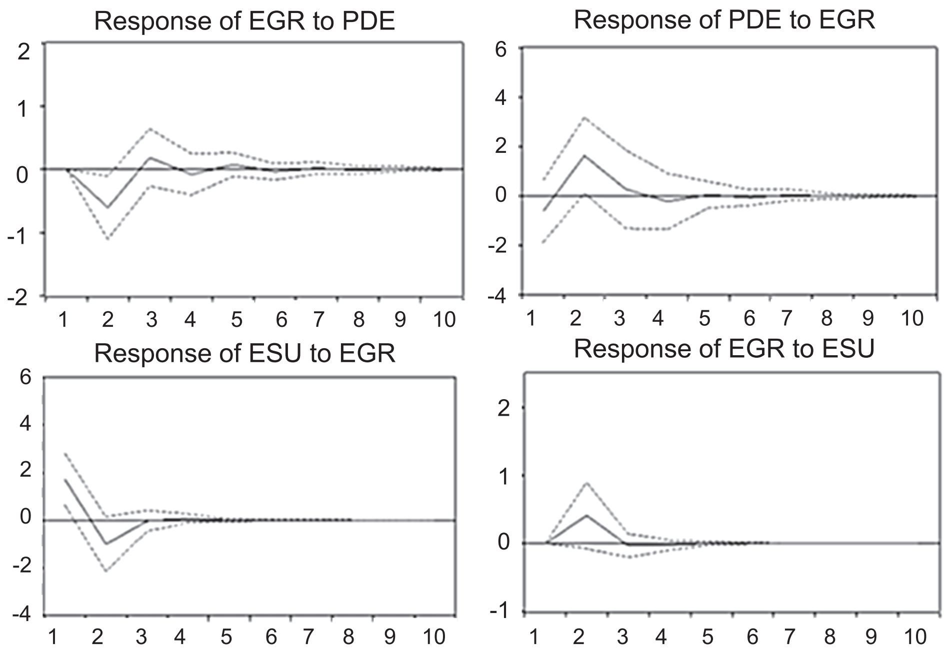
These findings highlight the importance of tailored policies. For highly indebted and energy-dependent countries, enhancing energy security and managing debt sustainably are crucial for economic stability. For less indebted and energy-independent countries, balancing energy production and imports while leveraging growth for debt management remains essential. This study provides insights for policymakers aiming to promote sustainable economic development and energy security across OECD European nations.

APPENDIX 1: BELGIUM RESULTS

APPENDIX TABLE 1: BELGIUM — GRANGER CAUSALITY (ACCORDING TO THE TODA-YAMAMOTO APPROACH)

Null hypothesis	Statistic	Prob.
PDE does not Granger Cause ESU	0.615	0.437
ESU does not Granger Cause PDE	0.186	0.667
EGR does not Granger Cause ESU	3.115	0.084
ESU does not Granger Cause EGR	2.942	0.093
EGR does not Granger Cause PDE	***7.7***	***0.022***
PDE does not Granger Cause EGR	4.9	0.087

APPENDIX FIGURE 1: BELGIUM — IMPULSE RESPONSE FUNCTIONS



APPENDIX TABLE 2: BELGIUM — VARIANCE DECOMPOSITION

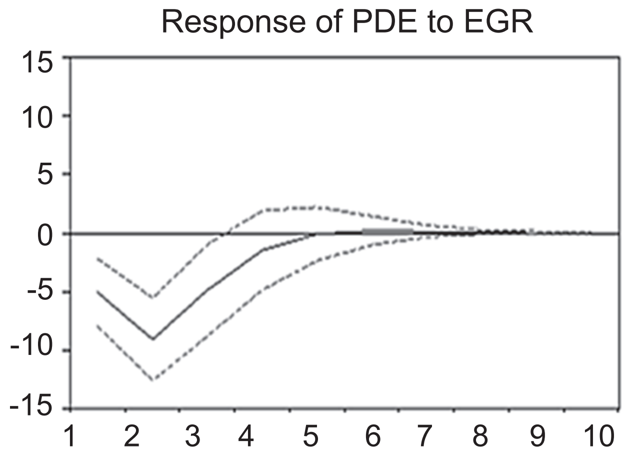
Variance decomposition of EGR	Period	EGR	PDE
Cholesky Ordering : PDE EGR	10	87.735	12.264
Variance decomposition of PDE	**Period**	**EGR**	**PDE**
Cholesky Ordering : EGR PDE	10	32.023	67.977

APPENDIX 2: FINLAND RESULTS

APPENDIX TABLE 3: FINLAND — GRANGER CAUSALITY

Null hypothesis	Statistic	Prob.
PDE does not Granger Cause ESU	0.209	0.651
ESU does not Granger Cause PDE	0.141	0.709
EGR does not Granger Cause ESU	0.215	0.645
ESU does not Granger Cause EGR	1.853	0.181
EGR does not Granger Cause PDE	***25.325***	***1.E-05***
PDE does not Granger Cause EGR	1.367	0.249

APPENDIX FIGURE 2: FINLAND — IMPULSE RESPONSE FUNCTIONS



APPENDIX TABLE 4: FINLAND — VARIANCE DECOMPOSITION

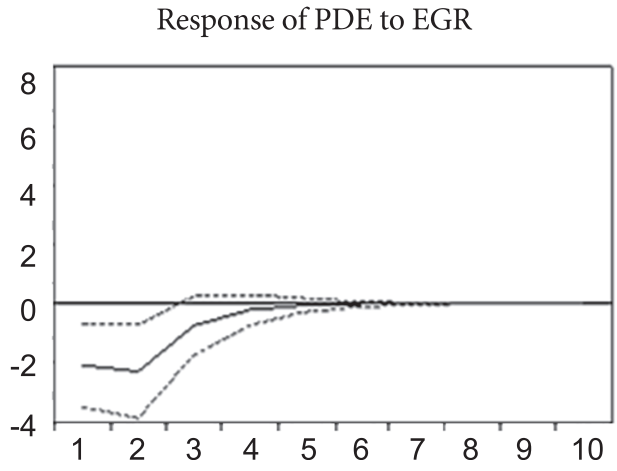
Variance decomposition of PDE	Period	EGR	PDE
Cholesky Ordering : EGR PDE	10	64.081	35.919

APPENDIX 3: GERMANY RESULTS

APPENDIX TABLE 5: GERMANY — GRANGER CAUSALITY

Null hypothesis	Statistic	Prob.
PDE does not Granger Cause ESU	1.833	0.181
ESU does not Granger Cause PDE	2.077	0.155
EGR does not Granger Cause ESU	1.020	0.317
ESU does not Granger Cause EGR	0.157	0.693
EGR does not Granger Cause PDE	***5.451***	***0.023***
PDE does not Granger Cause EGR	0.035	0.852

APPENDIX FIGURE 3: GERMANY — IMPULSE RESPONSE FUNCTIONS



APPENDIX TABLE 6: GERMANY — VARIANCE DECOMPOSITION

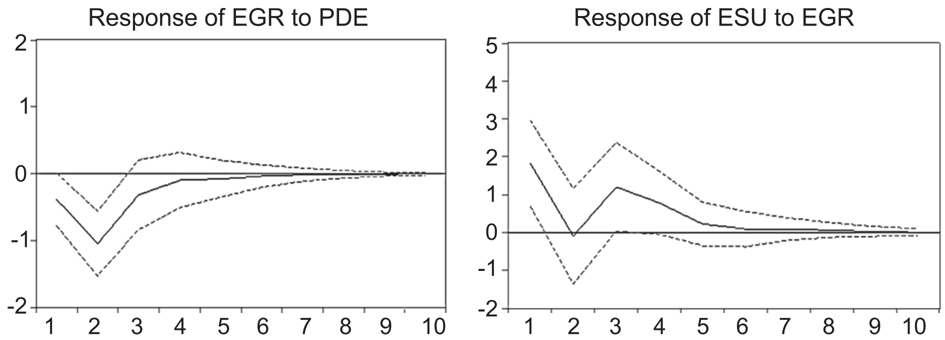
Variance decomposition of PDE	Period	EGR	PDE
Cholesky Ordering : EGR PDE	10	27.703	72.297

APPENDIX 4: THE NETHERLANDS RESULTS

APPENDIX TABLE 7: THE NETHERLANDS — GRANGER CAUSALITY

Null hypothesis	Statistic	Prob.
PDE does not Granger Cause ESU	0.601	0.552
ESU does not Granger Cause PDE	1.227	0.301
EGR does not Granger Cause ESU	2.537	0.089
ESU does not Granger Cause EGR	1.101	0.340
EGR does not Granger Cause PDE	1.174	0.317
PDE does not Granger Cause EGR	***9.178***	***0.0004***

APPENDIX FIGURE 4: THE NETHERLANDS — IMPULSE RESPONSE FUNCTIONS



APPENDIX TABLE 8: THE NETHERLANDS — VARIANCE DECOMPOSITION

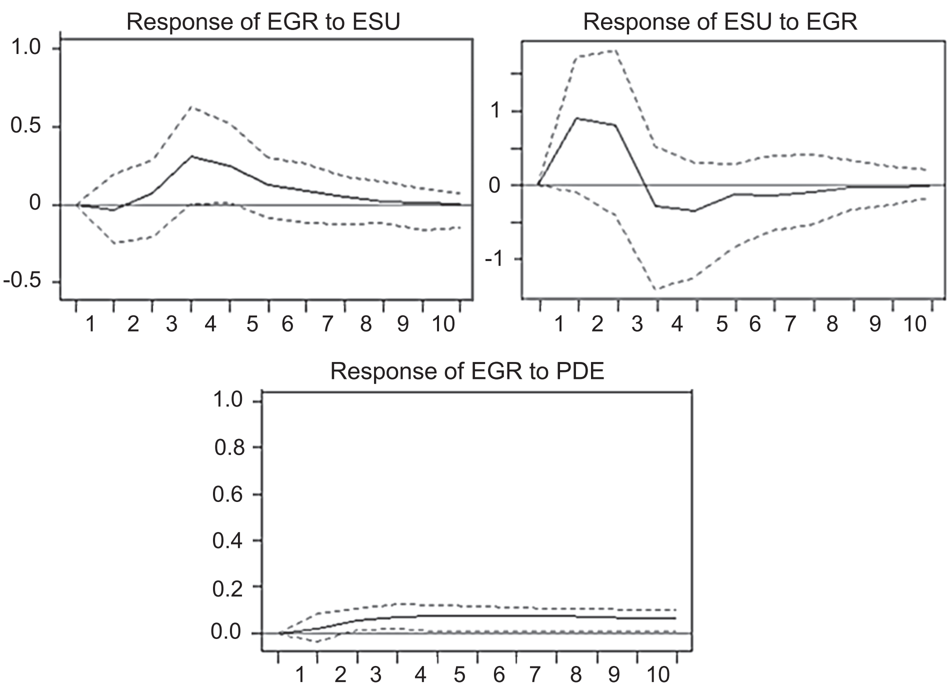
Variance decomposition of EGR	Period	EGR	PDE
Cholesky Ordering : PDE EGR	10	36.981	63.019

APPENDIX 5: SPAIN RESULTS

APPENDIX TABLE 9: SPAIN — GRANGER CAUSALITY (ACCORDING TO THE TODA-YAMAMOTO APPROACH)

Null hypothesis	Statistic	Prob.
PDE does not Granger Cause ESU	0.002	0.965
ESU does not Granger Cause PDE	1.574	0.218
EGR does not Granger Cause ESU	***6.8***	***0.03***
ESU does not Granger Cause EGR	***5.7***	***0.04***
EGR does not Granger Cause PDE	1.8	0.41
PDE does not Granger Cause EGR	***5.4***	***0.04***

APPENDIX FIGURE 5: SPAIN — IMPULSE RESPONSE FUNCTIONS



APPENDIX TABLE 10: SPAIN — VARIANCE DECOMPOSITION

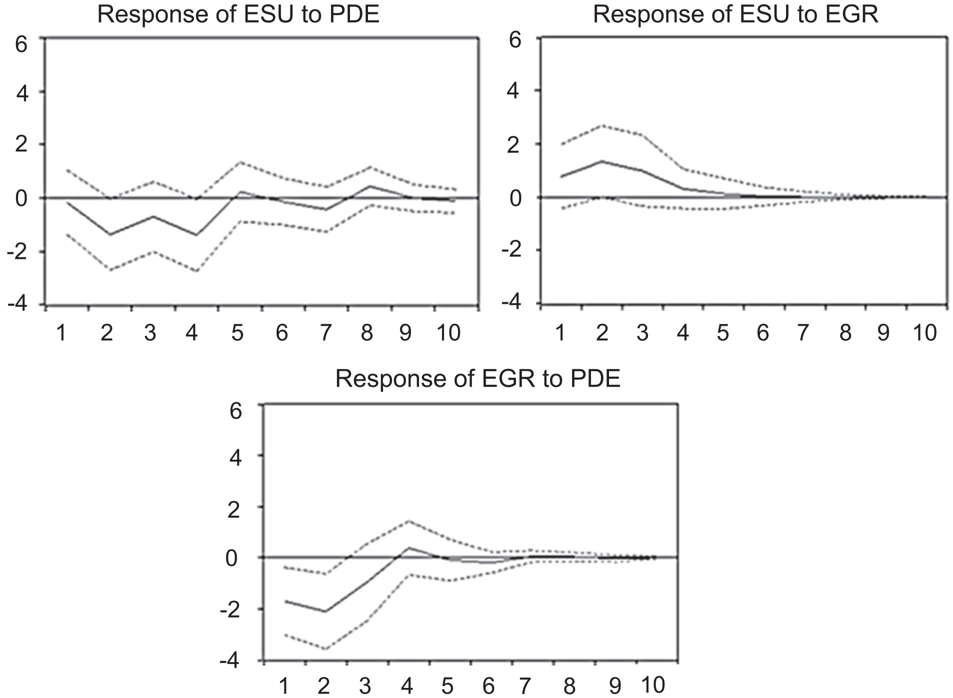
Variance decomposition of ESU	**Period**	**ESU**	**EGR**
Cholesky Ordering : EGR ESU	10	85.757	14.243
Variance decomposition of EGR	**Period**	**ESU**	**EGR**
Cholesky Ordering : ESU EGR	10	51.307	48.693
Variance decomposition of EGR	**Period**	**PDE**	**EGR**
Cholesky Ordering : PDE EGR	10	41.542	58.458

APPENDIX 6: IRELAND RESULTS

APPENDIX TABLE 11: IRELAND — GRANGER CAUSALITY

Null hypothesis	Statistic	Prob.
PDE does not Granger Cause ESU	***3.614***	***0.023***
ESU does not Granger Cause PDE	0.715	0.549
EGR does not Granger Cause ESU	***2.849***	***0.052***
ESU does not Granger Cause EGR	0.010	0.998
EGR does not Granger Cause PDE	1.624	0.203
PDE does not Granger Cause EGR	***3.067***	***0.041***

APPENDIX FIGURE 6: IRELAND — IMPULSE RESPONSE FUNCTIONS



APPENDIX TABLE 12: IRELAND — VARIANCE DECOMPOSITION

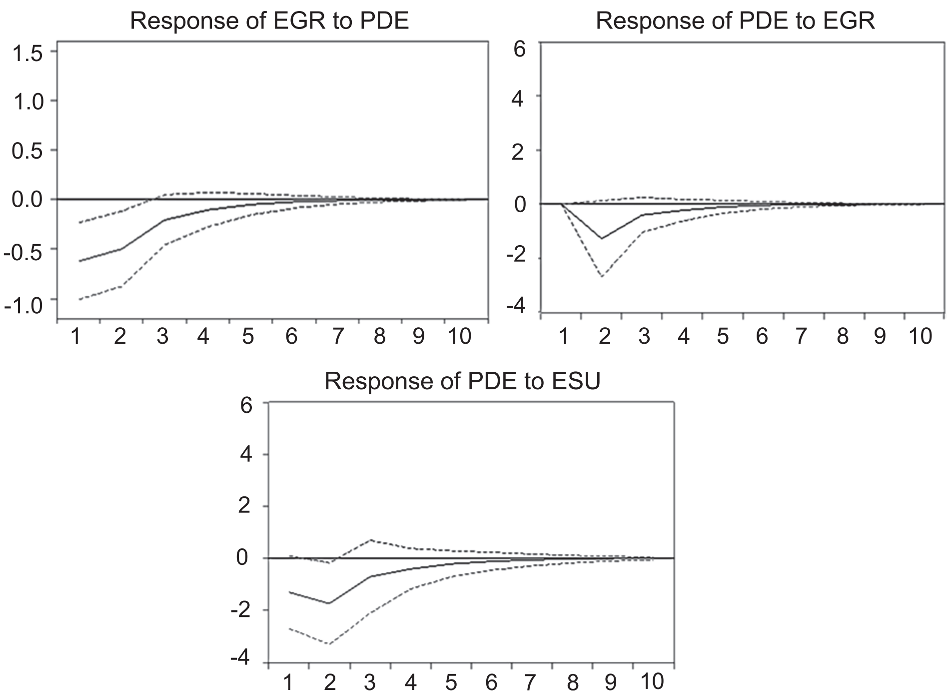
Variance decomposition of ESU	Period	ESU	EGR
Cholesky Ordering : PDE ESU	10	23.616	76.384
Variance decomposition of ESU	**Period**	**ESU**	**EGR**
Cholesky Ordering : EGR ESU	10	21.480	78.520
Variance decomposition of EGR	**Period**	**PDE**	**EGR**
Cholesky Ordering : PDE EGR	10	41.311	58.689

APPENDIX 7: FRANCE RESULTS

APPENDIX TABLE 13: FRANCE — GRANGER CAUSALITY

Null hypothesis	Statistic	Prob.
PDE does not Granger Cause ESU	0.079	0.780
ESU does not Granger Cause PDE	3.560	0.065
EGR does not Granger Cause ESU	0.146	0.704
ESU does not Granger Cause EGR	0.897	0.348
EGR does not Granger Cause PDE	3.423	0.071
PDE does not Granger Cause EGR	***4.175***	***0.047***

APPENDIX FIGURE 7: FRANCE — IMPULSE RESPONSE FUNCTIONS



APPENDIX TABLE 14: FRANCE — VARIANCE DECOMPOSITION

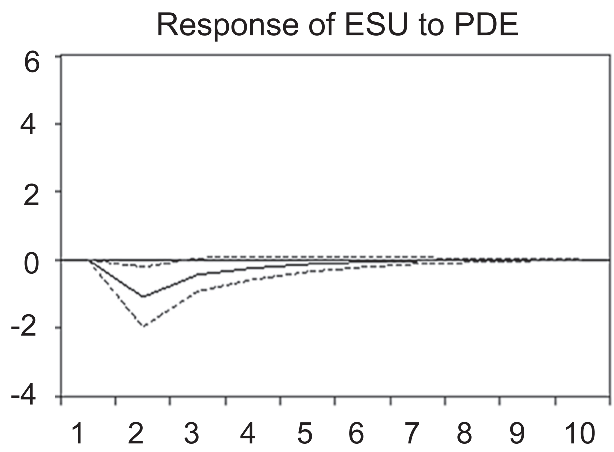
Variance decomposition of EGR	Period	PDE	EGR
Cholesky Ordering : PDE EGR	10	29.835	70.165

APPENDIX 8: ITALY RESULTS

APPENDIX TABLE 15: ITALY — GRANGER CAUSALITY

Null hypothesis	**Statistic**	**Prob.**
PDE does not Granger Cause ESU	***6.457***	***0.014***
ESU does not Granger Cause PDE	0.834	0.365
EGR does not Granger Cause ESU	0.695	0.407
ESU does not Granger Cause EGR	0.733	0.395
EGR does not Granger Cause PDE	0.643	0.426
PDE does not Granger Cause EGR	0.615	0.436

APPENDIX FIGURE 8: ITALY — IMPULSE RESPONSE FUNCTIONS



APPENDIX TABLE 16: ITALY — VARIANCE DECOMPOSITION

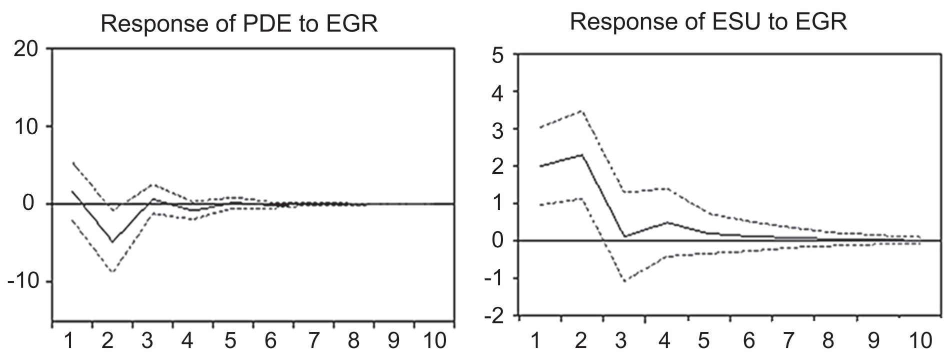
Variance decomposition of ESU	**Period**	**PDE**	**ESU**
Cholesky Ordering : PDE ESU	10	28.337	71.662

APPENDIX 9: GREECE RESULTS

APPENDIX TABLE 17: GREECE — GRANGER CAUSALITY

Null hypothesis	Statistic	Prob.
PDE does not Granger Cause ESU	0.038	0.844
ESU does not Granger Cause PDE	0.291	0.591
EGR does not Granger Cause ESU	***5.712***	***0.025***
ESU does not Granger Cause EGR	1.420	0.238
EGR does not Granger Cause PDE	***14.884***	***0.0003***
PDE does not Granger Cause EGR	0.0003	0.985

APPENDIX FIGURE 9: GREECE — IMPULSE RESPONSE FUNCTIONS



APPENDIX TABLE 18: GREECE — VARIANCE DECOMPOSITION

Variance decomposition of ESU	Period	EGR	ESU
Cholesky Ordering : EGR ESU	10	40.150	59.850
Variance decomposition of PDE	**Period**	**EGR**	**PDE**
Cholesky Ordering : EGR PDE	10	9.944	90.056

APPENDIX 10: GENERAL RESULTS

APPENDIX FIGURE 10: GROUPING OF COUNTRIES (DEBT AND GROWTH)

Group 1 – lowly indebted
- Group 1a - Germany, Finland (EGR-->PDE)
- Group 1b - Ireland, Netherlands (PDE-->EGR)

Group 2 – highly indebted
- Group 2a - France, Spain (PDE-->EGR)
- Group 2b - Belgium, Greece (EGR-->PDE)
- Italy (no causal relationship)

APPENDIX FIGURE 11: GROUPING OF COUNTRIES (ENERGY SUPPLY)

Group A – High energy dependence and a causality and/or towards energy supply.
- Spain, Italy, Greece, Ireland, Belgium

Group B – Energy independence and no causal relationshipand/or towards energy supply.
- Germany, Finland, Netherlands, France

APPENDIX TABLE 19: GRANGER CAUSALITY RESULTS[a]

Country	PDE→ ESU	ESU→ PDE	EGR→ ESU	ESU→ EGR	EGR→ PDE	PDE→ EGR
Belgium			*	*	**	*
Finland					***	
Germany					**	
Netherlands			*			**
Spain			**	**		**
Ireland	**		**			**
France		*			*	**
Italy	**					
Greece			**		***	

[a]*p<0.1; **p<0.05; ***p<0.01.

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