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Primary energy consumption and economic growth: the case of Greece

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Abstract
This paper examines the relationship between primary energy consumption and economic growth in Greece for the period 1965-2019 by using annual data. The main objective of this study is to investigate whether there is a causal relationship between economic growth and energy consumption. In terms of econometric specificity, ordinary least squares regression (OLS) is used to determine the model in the first step, while the vector self-regulating model (VAR) and the Wald test are used to detect causality. The study differs from the literature in terms of examining the individual energy sources. Total primary energy consumption in Greece is examined in relation to economic growth and individual energy sources separately. According to the results, primary energy consumption in Greece has a big impact on economic growth. The energy derived from non-renewable energy sources has the highest consumption rates. Causality tests show that there is a causal relationship between wind energy consumption and the GDP per capita while causality is observed from the GDP per capita to oil, coal, solar and hydropower consumption.

Keywords: energy consumption, economic growth, Greece, causality tests

Introduction

Energy is one of the most important goods for both consumers and producers. The literature that connects economic growth to energy consumption is extensive and the empirical findings determine ambiguous results on the direction of the causality effect. This relationship has also been studied for Greece (Donatos & Mergos, 1989; Tsani, 2010; Dergiades et al., 2013; Azam et al., 2016). The case of Greece, however, has been studied in comparison with other countries, both European (Aydin, 2019; Fuinhas et al., 2012) and Balkan (Georgantopoulos & Tsamis, 2011). Nowadays, due to the great energy crisis caused by the Russian invasion of Ukraine, there is an increasing need to examine energy-related issues and find solutions to topical issues. Increased international energy prices effect on all products and services as

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everything around us requires the use of energy in one way or another. This is naturally evident in the precision that arises from the continuous rise in energy prices and its subsequent impact on the economies of individual countries. That is why it is of particular importance to examine the relationship between energy consumption and growth as it has become particularly evident, especially in recent months, that there is a great interaction between these two economic aggregates.

In this paper, the relationship between economic growth and energy consumption depending on the source of energy (oil, gas, coal, solar, hydro and wind energy consumption) is examined. The country for which the study is conducted is Greece and the data used are annual data for the period 1965-2019.

Primary energy consumption measures the total energy demand of a country. It covers consumption of the energy sector itself, losses during transformation (for example, from oil or gas into electricity) and distribution of energy, and the final consumption by end users. It excludes energy carriers used for non-energy purposes (such as petroleum used not for combustion but for producing plastics).

Specifically, the relationship between primary energy consumption and the GDP growth for approximately 55 years is examined in this paper, including all available data regarding energy consumption by sector. An additional contribution of this study is the examination of the relationship according to the source of energy, which allows researchers and policy makers to focus on energy policies that will benefit the economy considering the environment and the sustainable growth. Examining the issue by taking into account the origin of energy is relevant, as in recent years policies around the world have been promoted so as to use renewable energy sources and reduce fossil fuel energy consumption.

The main results of this study indicate that there is not causality effect between primary energy consumption and real GDP per capita and that there is not causality effect between real GDP per capita and primary energy consumption from gas (for simplicity reasons, from this point on the authors will use the term “GDP” and denote “the real GDP per capita”). However, causality effects from GDP to primary energy consumption from GDP to oil, from GDP to coal, from GDP to hydro, from GDP to solar and from wind to GDP are observed. In the literature to date, to the knowledge of the authors, there are no studies showing causalities between economic growth and energy consumption by taking into account the energy source for Greece. However, there are similar studies for other countries, such as Carmona et al. (2017) for the U.S.A. and Vlahinić and Zikovic (2010) for Croatia.

The remainder of this paper is organized as follows: Section one provides an overview of the energy sector in Greece, the literature review is presented in section two and the data are described in section three. In section four the methodology is analysed; in section five, the empirical results are presented and finally, in section six, the concluding remarks are discussed.

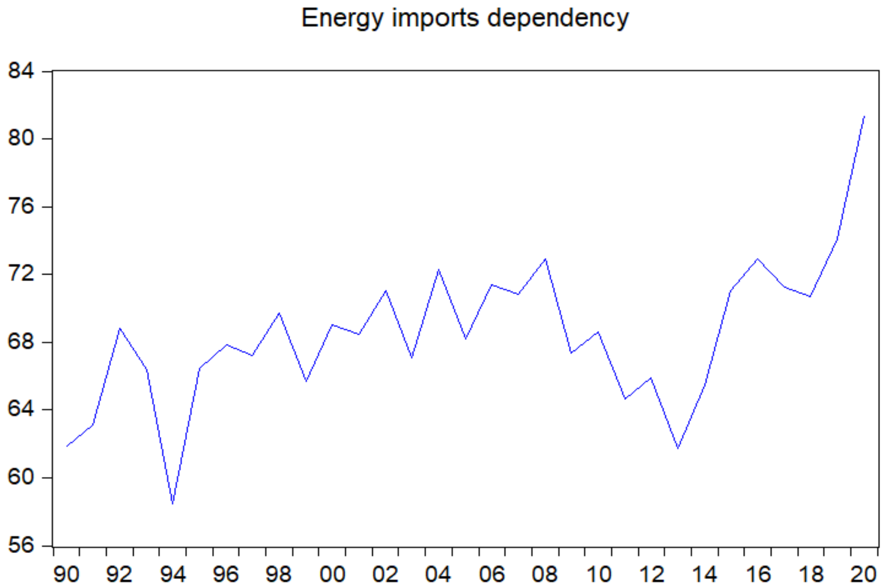
1. The Greek energy sector

The energy sector is one of the most important in a country and directly and indirectly affects its economy. In Greece, energy sources such as oil, natural gas, coal, electricity, biomass, biofuels, wind, solar, hydroelectric, heat (pumps) and other Renewable Energy Sources (RES) are either imported or produced. The largest percentages of energy consumption in the country come from fossil fuel-sourced energy, or otherwise non-renewable energy sources but, in recent years, Greece, like most countries, has been following the global trend of promoting policies that will enhance the RES energy consumption. The objectives and policies pursued by the country in this direction are mostly, of course, those promoted by the European Union. The regulatory authority responsible for overseeing and regulating the energy sector in Greece is the Energy Regulatory Authority (RAE, 2023).

Greece's energy needs are mainly covered by imports of primary energy (oil and natural gas), and to a lesser extent by domestic production of solid fuels and RES. In other words, the country is heavily energy-import dependent as the largest percentages of energy consumption come from fossil fuels, which accounts for the magnitude of greenhouse gas emissions. In general, the energy sector has been the main source of gas emissions over time, due to the high participation of lignite and oil in the production of electricity. However, in recent years, due to the strengthening of the use of energy from renewable energy sources, these indicators have tended to decrease (IOBE, 2020).

The country's energy import dependence on imports is clearly shown in Figure 1. Energy imports dependency refers to the extent to which a country relies on energy imports from other nations to fulfil its overall energy requirements. This measure indicates the proportion of energy that a country must import, and it is calculated by dividing net energy imports by the total available energy, expressed as a percentage. This dependency rate can be determined for both the entire range of energy products and specific fuels, such as crude oil and natural gas. The time series in Figure 1 presents Greece’s energy dependence on energy imports from 1990 to 2020 in more detail. It is observed that, in recent years, the rates of energy import dependence are steadily rising and that the country is directly dependent on energy imports to meet its energy needs. The increasing demand for energy in combination with the growth of the industrial sector and tourism in the country is driving up the need for energy imports. Additionally, the high demand for fossil fuels such as oil and natural gas (which have the highest consumption rates in the country as shown in Figure 5) could justify the upward trend in energy imports, as Greece is not among the oil and natural gas-exporting nations.

Figure 1. Energy imports dependency



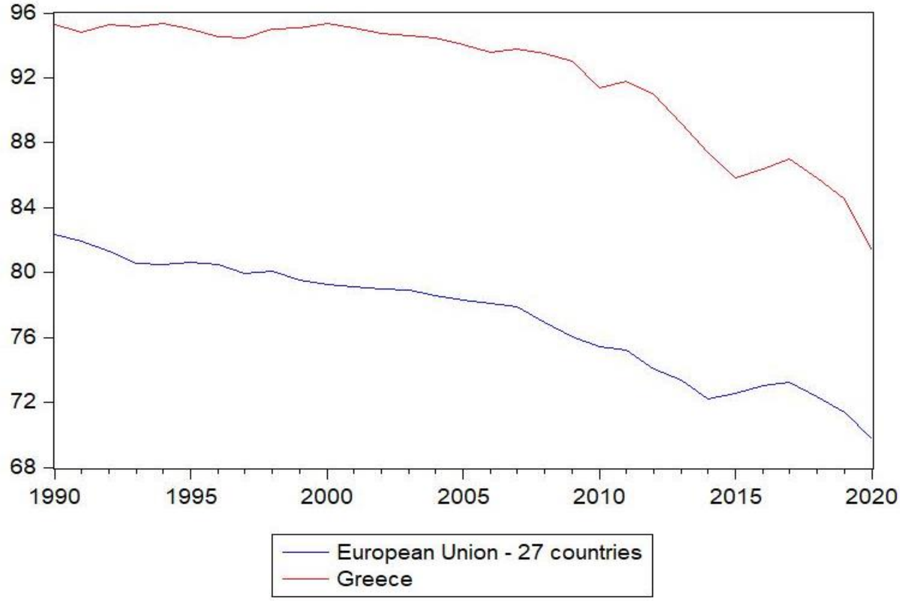
Source: Eurostat (2022a)

Following the above, Figure 2 shows the time series on the share of fossil fuels in gross available energy for the last 30 years, approximately, for Greece and the European Union, to indicate the trend towards a reduction in fossil fuel energy consumption. It is observed that, after 2009, the country follows a continuous downward trend, but the rates of dependence and use of energy from fossil fuels remain high, as shown in the following analyses. In addition, along with the downward trend of the share of fossil fuels in the gross available energy, it is particularly useful to show the upward trend of the corresponding share of energy from renewable sources. Both Greece and the EU average display similar behaviour through the years.

The reduction in the share of fossil fuels in the total available energy in recent years could be a result of the relevant legislation in the country and the EU for the energy transition and consumption of energy from renewable sources. In Greece, the use of energy from renewable sources was first introduced in its legal framework in 1994 by Law 2244/1994, which established the legal framework to produce electricity from renewable sources. A few years later, in 1999, Law 2773/1999 promoted the use of renewable energy sources, while in 2006, Law 3468/2006 promoted the generation of electricity from renewable energy sources. The incorporation of the European Union's Renewable Energy Directive into Greek law (Law 3851/2010) and its target for Greece to reach 18% of final energy consumption from renewable sources by 2020 could also be a factor in this reduction.

Furthermore, Law 4414/2016, which amended and updated the legal framework for renewable energy sources in Greece, and the legislation and continuous amendments in the period from 2018 until today, likely contributed to this decrease.

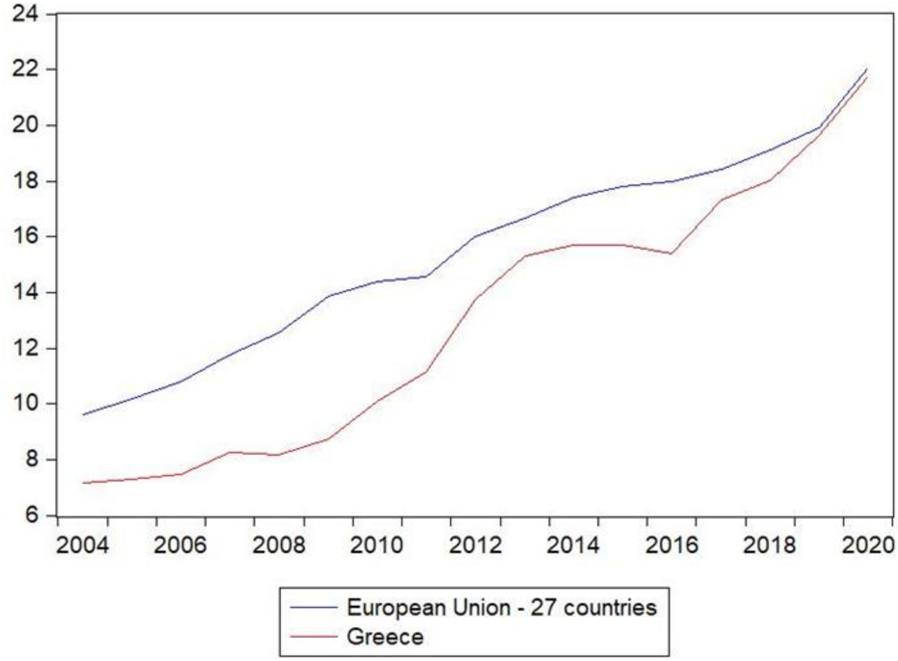
Figure 2. Share of fossil fuels in gross available energy



Source: Eurostat (2022b)

Figure 3 shows the time series on the share of energy from renewable sources for the years 2004 to 2020 for Greece and European Union. The share of energy from renewable energy sources for Greece is observed to occur at a significantly later stage as the emergence and use of energy from renewable energy sources in the country took place in recent years. However, Greece has fully aligned with the EU average. Hence, we possess data starting from 2004 onwards. It is also observed that the share of energy use from renewable energy sources is constantly increasing over the years, however the percentages of this indicator remain quite low for Greece in relation to the corresponding percentages of the share of fossil fuel-sourced energy. This fact once again confirms the country's energy import dependence.

Figure 3. Share of energy from renewable sources



Source: Eurostat (2022c)

As obvious in Figures 2 and 3, following the European Union's directives, Greece is in favour of energy transition and of increasing the use of energy from renewable sources. This underscores the significance of examining the connection between energy consumption and economic growth, with a focus on the energy source.

2. Literature review

In recent years, more and more researchers have been studying the relationship between economics and energy consumption. There are relevant studies in the literature throughout the years, with different data sets and time periods, which differ in terms of method (Al-mulali et al., 2013; Destek & Aslan, 2017; Tsani, 2010), country (Lise & Van Montfort, 2007; Zhang & Cheng, 2009), or countries (Bozoklu & Yilanci, 2013; Kasperowicz & Štreimikienė, 2016). There are also studies that approach this issue from a completely transparent perspective and make comparisons between different countries.

In recent years, in relevant studies for both Greece and other countries, methods such as Granger Causality & Causality Analysis Techniques (Ozcan & Ozturk, 2019; Audin, 2019), Vector Error correction Models (VECM) (Pao & Chen, 2019), Vector Autoregressive Models (VAR) (Antonakakis et al., 2017) and ARDL models have been used (Cai et al., 2018; Alola et al., 2019). More specifically, studies that included data for Greece, Donatos and Mergos (1989) and Lise and Van Montfort (2007), studied the relationship between GDP and energy consumption for Greece and Turkey, respectively, with linear models. ECM and VECM are quite widespread in such analyses. Hondroyiannis et al. (2002) and Azam et al. (2016) studied the case of Greece by using annual data and, due to the analysis of VECM models, important policy implications are proposed. On the other hand, in the case of a study including many countries, the VECM or VAR panels are used. Cases of studies using these models are those of Mahadevan and Asafu-Adjaye (2007) and Huang et al. (2008), which examined the ratio of growth and energy consumption for several countries simultaneously.

In the literature, the relationship between growth and energy consumption has been studied for many countries, individually and by comparison, as well. Several researchers were involved in this topic by studying groups of countries at the same time in order to check the results in these countries for the same period of time and by using the same econometric method. Ozturk and Acaravci (2010) investigated the causal relationship between energy and economic growth in Albania, Bulgaria, Hungary and Romania from 1980 to 2006 by using variables of energy use per capita, electricity consumption per capita and GDP. They concluded that there is aggregation among the variables only for Hungary and that there is none in the other three countries. This analysis showed that any causal relationships cannot be estimated under the dynamic error correction model for Albania, Bulgaria and Romania.

In another study, Acaravci and Ozturk (2010) investigated the long-term relationship and causality issues between electricity consumption, this time, and economic growth in 15 countries (Albania, Belarus, Bulgaria, Czech Republic, Estonia, Latvia, Lithuania, FYROM, Moldova, Poland, Romania, Russian Federation, Serbia, Slovak Republic and Ukraine). The method used was the Pedroni panel cointegration method and the results showed that a long-term balance relationship between electricity consumption per capita and real GDP per capita is not confirmed. An even larger sample of countries was studied by Destek and Aslan (2017). By using annual data from 1980 to 2012, this study investigated the relative performance of renewable and non-renewable energy consumption in economic growth in 17 emerging economies. The results were different for each case.

Georgantopoulos and Tsamis (2011) focused on the Balkan countries. More specifically, they used data from Greece, Bulgaria, Romania and Albania during the period 1980-2009. The results of the Granger causality test using VAR estimates and the error correction model suggest that there is a one-way causality running from GDP to energy consumption for Greece. For Bulgaria and Romania, the data show unidirectional causal links ranging from energy consumption to GDP, and this means that energy consumption can be considered as the main indicator of economic growth for these two Balkan countries. Finally, the empirical results for Albania suggest that energy consumption and GDP are independent.

Many researchers worldwide have examined the relationship between energy consumption and economic growth by studying groups of countries. The number of countries studied in each case is not the same, and the results vary, as countries, time-period, and methodology differ. Mahadevan and Asafu-Adjaye (2007) examined the relationship between energy consumption and growth in a panel error correction model using data on 20 net energy importers and exporters from 1971 to 2002. They concluded that, among energy exporters, there was a two-way causality between economic growth and energy consumption in developed countries both in the short and in the long term while in developing countries, energy consumption was seen to grow only in the short term. In the second stage they showed that, compared to developing countries, the flexibility response of developed countries in terms of economic growth from the increase in energy consumption is greater. Studying almost the same period, namely 1972-2002, but on a much larger sample of countries, Huang et al. (2008) studied the issue of energy consumption and growth. They used panel data for 82 countries and categorized countries into four main income-based categories as defined in the World Bank. The countries were categorized into low-income, lower-middle-income, upper-middle-income, and high-income countries. According to the results in the low-income group, there was no causal relationship between energy consumption and economic growth, in the middle-income groups (lower and upper middle-income groups), economic growth was driving energy consumption positively, and in the countries of the high-income group, economic growth was driving energy consumption negatively.

In their study, Al-mulali et al. (2013) added two additional factors, i.e. urbanization and CO^2 emissions. The group of countries examined for the period 1980-2009 was MENA[1] and the results showed that urbanization, energy consumption and CO^2 emissions are integrated, and the dynamic OLS results also showed that there was a long-term two-way positive relationship between urbanization, energy consumption and CO^2 emissions. In addition, long- and short-term bidirectional causal relationships were found between the variables based on the results of Granger causality tests.

Furthermore, there are more recent studies on the relationship between renewable energy consumption, non-renewable energy consumption, and economic growth. Kravchuk et al. (2019) analyse the latest research on alternative energy in advanced countries, compare energy consumption and efficiency in Ukraine with that of EU countries, and evaluate the growth of renewable energy in the EU and its

[1] MENA countries refer to the countries located in the Middle East and North Africa region. These countries are Algeria, Bahrain, Djibouti, Egypt, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Libya, Morocco, Oman, Palestine, Qatar, Saudi Arabia, Sudan, Syria, Tunisia, United Arab Emirates, and Yemen.

energy balance. Gyimahet al. (2022) explore the impact of renewable energy on economic growth in Ghana, finding a positive total effect on economic growth. Baz et al. (2021) investigate the nexus between fossil fuel, renewable energy, and economic growth in Pakistan, emphasizing the importance of clean energy for sustainable economic growth. Fareed and Pata (2022) analyse the impact of renewable and non-renewable energy consumption on economic growth in the top ten renewable energy-consuming countries, highlighting the need to reduce fossil fuel use and deploy renewables strategically. Mohammadi et al. (2023) examine the relationship between energy consumption and economic growth in developed and developing countries, identifying a positive effect of energy consumption on economic growth and suggesting the importance of independent growth policies. Finally, González-Álvarez and Montañés (2023) explore the stability of the relationship between CO^2 emissions, energy consumption, and economic growth, finding decoupling of CO^2 emissions from economic growth in most countries but an intensified relationship between CO^2 emissions and energy consumption, indicating the need for cleaner energy production methods. Overall, these studies underscore the significance of renewable energy and energy consumption policies in promoting sustainable economic growth while addressing environmental challenges.

Moreover, in the literature, there are several studies related to the case of Greece. One of the first studies on energy consumption and growth for Greece, using numerous econometric models, was Samouilidis and Mitropoulos (1984). The Translog functions contributed to finding that energy income and price elasticities showed downward trends over time. The results showed that in an industrialized country like Greece, energy policymaking would be of low efficiency until some structural changes were made to the economy. In their paper, Donatos and Mergos (1989) examined the impact of the two energy crises, 1973-1974 and 1978-1979, on energy demand in Greece. Examining the demand parameters for hydroelectric, liquid and solid fuels for the period 1963-1984, they showed that while consumption patterns may be different due to changes in prices and incomes after the crisis, the parameters of energy demand in Greece remained unchanged.

The relationship between energy consumption and growth for Greece was also studied by Hondroyiannis et al. (2002), examining the period 1960-1996 and applying an error correction model (ECM). The assessment included energy consumption, GDP and price developments, considered to represent a measure of economic efficiency, and the results showed that there is a long-term relationship between the three variables, supporting the endogeneity of energy consumption and actual production. Tsani (2010) studied the causal relationship between aggregate and disaggregated levels of energy consumption and economic growth for Greece. The period studied was from 1960 to 2006 and the method used was a later development of the time series methodology proposed by Toda and Yamamoto (1995). According to the results, there has been a unidirectional causal relationship ranging from total energy consumption to GDP and empirical evidence has shown that there is a two-way causal relationship between industrial and domestic energy consumption with GDP, but this does not apply to energy consumption from transport with a causal relationship located in either direction.

The case of Greece was also studied by other researchers by using other econometric methods and different data from other periods. Dergiades et al. (2013) contributed to the understanding of the linear and nonlinear causal relationship between energy consumption and economic growth. Studying the case of Greece for the period 1960-2008, they investigated whether the total energy consumption has been adjusted for qualitative differences between its constituent components through the thermodynamics of energy conversion. According to the results, there were significant unidirectional, both linear and nonlinear, causal connections from total useful energy to economic growth.

Focusing on electricity consumption, Georgantopoulos (2012) studied the existence and direction of causality between electricity consumption and real gross domestic product for Greece for the period 1980-2010. The results showed that all variables are integrated of the First Order and the synthesis analysis states that there is a synthesis relationship between the variables, while the VAR/VEC approach showed that the variables return to long-term equilibrium whenever there is a deviation from the integrative relationship and that there are unidirectional causal links ranging from capital creation and electricity consumption to GDP in the short term, implying that Greece's economy is strongly dependent on energy. Polemis and Dagoumas (2013) also focused on the relationship of electricity consumption and growth for Greece. Using a vector error correction model and data from 1970 to 2011, they attempted to capture short-and long-term dynamics. They showed that, in the long run, electricity demand is inelastic in terms of prices and elastic in terms of income while, in the short run, relative elasticities are below unity. They also argue that the causal relationship between electricity consumption and economic growth in Greece is two-way. This research reinforced the view that Greece is an energy import dependent country and well-directed energy saving policies could even stimulate economic growth.

However, there are also papers on the case of Greece approaching the issue from another perspective. One of these studies is by Azam et al. (2016), who identified and evaluated the macroeconomic factors that determine energy consumption in Greece. Using data for the period 1975-2013 and applying a vector error correction model, they showed that, in order to meet the energy demand in the country, decision-makers must formulate energy policy in favour of expanding energy supply and especially renewable energy sources to promote the process of economic growth and development. Especially, in times of crisis, these determinants are a necessity for the start of economic growth. From a quite different perspective, Roinioti and Koroneos (2017) approached the issue of energy and economics. They attempted to identify the driving forces of CO^2 emissions related to energy consumption, through the use of the complete decomposition technique developed by JW Sun. Focused on CO^2 emissions, the analysis was centred on four factors: the carbon intensity effect, the energy intensity effect, the structural effect and the economic activity effect. Covering all major productive sectors of the Greek economy, the period 2003-2013 was examined and divided into two subperiods (2003-2008 and 2008-2013) in order to assess the changes in the contribution of the examined factors during the economic crisis (2008-2013).

Examining a long period of time for Greece, from 1990 to 2016, Pegkas (2020) investigated the relationship between renewable and non-renewable energy consumption and economic growth. The findings of the survey showed that there is a significant positive long-term effect of both renewable and non-renewable energy consumption on economic growth while in the short term, the results are in the same direction. Considering the overall results, the consumption of renewable and non-renewable energy sources significantly stimulates economic growth in Greece. Also, taking into account that renewable energies reduce carbon dioxide emissions and protect the environment, the consumption of renewable energy according to a strategic plan became necessary.

Considering the available literature, this paper focuses on examining the correlation between primary energy consumption and economic growth in Greece, with particular emphasis on the energy source.

3. Methodology

The methodology of the paper is based on the vector autoregressive model and causality effect among GDP and energy consumption by sector. For this methodology, we first test the stationarity of time series according to Dickey & Fuller (1979; 1981) because the causality analysis requires time series to be stationary. The next step is to test the number of lags for the VAR model, and we employ the lag length criteria for the models, the choice being based on the Akaike information criterion. Finally, we employ the VAR model and the Granger Causality based on Block Exogeneity Wald Tests. For the analysis, the EViews software is used for the empirical applications.

3.1. The VAR Model

For the empirical results, a basic VAR model is employed. The Vector autoregression model is used to study the relationship among GDP and primary energy consumption, primary energy consumption from oil, gas, coal, solar, hydro and wind.

The specification of a basic VAR model can be described in the following equations:

$$Y_t = \alpha_0 + \sum_{i=1}^{\kappa} \alpha_{1i} Y_{t-i} + \sum_{i=1}^{\kappa} \alpha_{2i} X_{t-i} + u_{1t}$$

$$X_t = b_0 + \sum_{i=1}^{\kappa} b_{1i} X_{t-i} + \sum_{i=1}^{\kappa} b_{2i} Y_{t-i} + u_{2t}$$

where Y_t is the GDP, X_t is the primary energy consumption from oil, gas, coal, solar, hydro and wind, respectively in each model, a and b are defined as the parameters and k denotes the number of lags.

4. Data description

The annual data on energy consumption for Greece used in the study are measured in terawatt-hours (TWh) for the years 1965-2019 and derived from the database ourworldindata (Ritchie et al., 2022). The constant GDP per capita data for Greece comes from Fred's database (FRED, 2022) (expressed in millions, in constant prices). The descriptive statistics of the natural logarithms of the variables are shown in Table 1. Most variables have 55 observations while some have fewer, which is due to the subsequent emergence of some forms of energy in the country; for example, the use of renewable energy sources applies in recent years only. In addition, any negative values are justified because the data are expressed in natural logarithms.

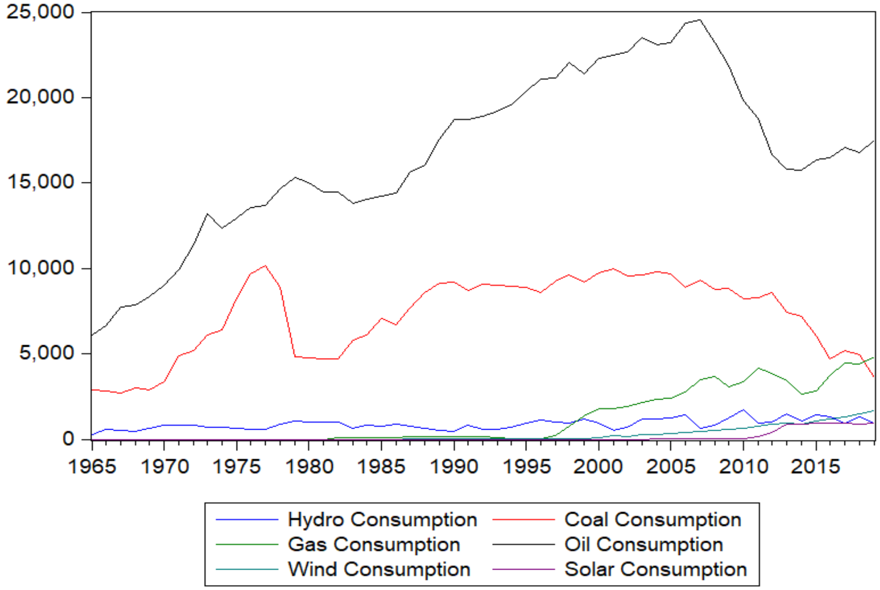
Table 1. Descriptive statistics

	N	Mean	Std. Dev.	min	max
GDP	55	9.663	0.267	8.929	10.089
Oil	55	9.671	0.337	8.718	10.107
Gas	38	6.534	1.694	3.878	8.477
Coal	55	8.816	0.392	7.898	9.224
Solar	16	3.697	3.583	-1.425	6.833
Hydro	55	6.723	0.356	5.562	7.467
Wind	33	4.246	2.900	-1.29	7.427
Primary Energy	55	10.124	0.362	9.131	10.56

Note: Variables are defined in natural logarithms.
Source: authors' calculations

Energy consumption by sector in Greece is shown in Figure 4, expressed in kilowatt-hours (kWh). Time series on energy consumption of coal, natural gas, hydroelectric power, oil, solar, energy and wind are shown.

Figure 4. Energy Consumption by sector (PivotChart)



Source: authors' representation based on Ritchie et al. (2022) data

Due to the large consumption differences and for better visualization of price evolution, each sector is presented, separately, in Figure 5. It is evident from the graph that some forms of energy that appeared in recent years have a strong upward trend even though their consumption rates are still low. These forms come from renewable energy sources and are hydroelectric power, wind and solar.

However, the highest consumption among all occurs in oil energy consumption (Figure 5d), which consistently remains at high levels over the years. Quite high is also the energy consumption of coal (Figure 5a) and natural gas (Figure 5b) follows. Observing the energy sectors with the highest consumption in kilowatts-hours in Greece, it seems that their consumption was drastically affected only during periods of crisis. More specifically, for the consumption of petroleum energy, which has the highest consumption rates, strong fluctuations occurred during the constraints of the oil crises (1973 & 1979), the global economic recession (2010) but also in the Covid-19 pandemic crisis (2020). On the other hand, the coal energy consumption, which comes second in terms of consumption levels, has been markedly downward in recent years. This is particularly encouraging as, in recent years, policies have been promoted in favour of renewable sources energy consumption, reducing the use of energy from non-renewable sources. In addition, the consumption of gas energy has been increasing in recent years.

Figure 5. Energy Consumption by sector

Source: authors' representation based on Ritchie et al. (2022) data

This is justified by its lower price compared to other energy sources; nevertheless, this should be seriously taken into account in policymaking. All the above show that fossil fuels energy consumption has been and still remains high, but that there is an increasing trend of energy consumption from renewable energy sources. The increasing trend of renewable energy sources is also shown in Figures 5c, 5e and 5f pointing to energy consumption from hydropower, wind and solar, respectively.

5. Empirical Results

5.1. Regression analysis

The results of the regressions are indicated in Table 2. Models 1 to 7 illustrate the impact on GDP resulting from a percentage change in energy consumption, both overall and within specific sectors. In detail, the extent to which the consumption of all individual forms of energy affects the country's economy. Robust standard errors are used to obtain robust tests for the analysis.

The second column of Table 2 presents the results of the first model which examines the relationship between GDP and primary energy consumption in Greece from 1965 to 2019. It is observed that a percentage increase in primary energy consumption leads to a corresponding 0.7% increase in GDP. Models 2 through 7 examine the relationship between GDP and energy consumption per sector. Specifically, Model 2 presents the relationship between GDP and oil energy consumption for the period 1965-2019. According to the results, a percentage increase in oil energy consumption leads to a corresponding 0.74% increase.

Model 3 examines the relationship between GDP and gas energy consumption for the period 1982-2019. It is concluded that a percentage increase in gas energy consumption would result in 0.07% GDP increase.

The relationship between GDP and coal energy consumption is described in Model 4 by using data for the period 1965-2019. It is observed that a percentage increase in coal energy consumption leads to a corresponding 0.48% increase in GDP, with a significance level of 1%.

Model 5 describes the relationship between GDP and solar energy consumption for the period 2004-2019. It is observed that, if increased by one unit, the consumption of solar energy will result in a 0.03% GDP decrease. This result may seem contradictory at the first sight, but there are many economic interpretations that could justify it. For example, the cost of using solar energy is likely to be quite high in the country, thus making it still unprofitable or, on the other hand, lacking in the appropriate institutional framework that could promote the use of solar energy and normalize the market in this sector. This finding needs special investigation as Greece is a country with quite high rates of sunshine and appropriate infrastructure, benefitting from a legal-institutional framework that supports this activity and incentives through grants to individuals which could very easily contribute positively to the wider economy and environmental protection.

The relationship between GDP and hydraulic energy consumption for 1965-2019 is described in Model 6 of Table 2. The results show that a percentage increase in hydraulic energy consumption will result in a GDP increase of about 0.47% at a materiality level of 1%.

Finally, Model 7 describes the relationship between GDP and wind energy consumption for 1987-2019 and we note that if it increases by one percentage point, wind energy consumption will increase by 0.036 % to GDP.

R-square is a statistical measure that represents the proportion of the variance for a dependent variable explained by an independent variable or variables in a regression model. So, in the first model, the variance of GDP can be explained by 0.92% from the variance of primary energy consumption. According to the results, it is overall observed that there is a strong positive relationship between primary energy consumption and economic growth in the country.

Table 2. Regression Analysis

VARIABLES	GDP	GDP	GDP	GDP	GDP	GDP	GDP
Primary _ Energy	0.7083***						
	(0.023)						
Oil		0.7439***					
		(0.029)					
Gas			0.0744***				
			(0.008)				
Coal				0.4887***			
				(0.076)			
Hydro					0.4795***		
					(0.080)		
Solar						-0.0303***	
						(0.003)	
Wind							0.0361***
							(0.004)
Constant	2.4910 ***	2.4681 ***	9.3042 ***	5.3535 ***	6.4388 ***	10.0261***	9.6662 ***
	(0.231)	(0.279)	(0.049)	(0.683)	(0.555)	(0.020)	(0.013)
Observations	55	55	38	55	55	16	33
R^2	0.9247	0.8840	0.6743	0.5156	0.4098	0.8608	0.5305

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%.
Source: authors' calculations

Observing the results succinctly, it seems that energy consumption derived from petroleum products and coal, or better fossil fuels has a greater impact on the economy than renewable energy sources such as solar, wind, and hydropower are considered as viable alternatives.

5.2. Unit root tests

The first step in the empirical analysis is to test the stationarity of time series, for which the unit root test is applied (Dickey & Fuller, 1979; 1981). From Table 3, it is observed that the variables GDP, consumption of primary energy, consumption of hydraulic energy and wind energy consumption are stationary I(0).

Using the first differences, GDP, primary energy consumption, oil consumption, gas consumption, coal consumption and hydro consumption are stationary I(1). Solar energy consumption is I(2) stationary. In addition, with the use of the first differences, wind consumption is non-stationary. The number of lags on the ADF test are based on AIC (Akaike information Criteria).

Table 3. Unit root tests

Variable / Test	***Lags***	***Augmented Dickey – Fuller test statistic***
GDP	1	-2,831442 (0.0607)
Primary energy consumption	1	-3,121093 (0.031)
Oil consumption	1	-2,042586 (0.5649)
Gas consumption	2	-3,227378 (0.7484)
Coal consumption	0	-1,803736 (0.3749)
Solar consumption	1	-2,046012 (0.2662)
Hydro consumption	1	-4,693325 (0.0003)
Wind consumption	4	-6,006403 (0.000)
First Differences		
GDP	0	-3,677135 (0.0073)
Primary energy consumption	0	-4,2309 (0.0014)
Oil consumption	0	-5,188808 (0.0005)
Gas consumption	1	-3,633082 (0.01)
Coal consumption	0	-5,070153 (0.0001)
Solar consumption	0	-1,560301 (0.4753)

Hydro consumption	1	-8,108539 (0.0000)
Wind consumption	6	-0,94371 (0.7568)

Source: authors' calculations

The results of the unit root test are necessary, as to proceed with causality tests; we need to know whether the variables are stationary.

5.3. Causality

The results of the VAR model are presented in Table 5 in the Appendix section. The results of Causality tests, as presented in Table 4, indicate that there is no causality effect between primary energy consumption and GDP. Also, there is no causality effect between GDP and primary energy consumption from gas. The causality effect from GDP to primary energy consumption from GDP to oil, from GDP to coal, from GDP to solar, GDP to hydro and from wind to GDP is observed. Similar results were found in surveys of other countries (Vlahinić & Zikovic, 2010).

Table 4. VAR Granger Causality / Block Exogeneity Wald Tests

	x^2		x^2
Primary energy → GDP	3.568926 (0.1679)	*GDP → Primary energy*	0.277323 (0.8705)
Oil → GDP	1.003006 (0.6056)	*GDP → Oil*	15.56759*** (0.0004)
Gas → GDP	0.945030 (0.6234)	*GDP → Gas*	1.543712 (0.4622)
Coal → GDP	0.777001 (0.6781)	*GDP → Coal*	4.697509* (0.0955)
Solar → GDP	1.931075 (0.3808)	*GDP → Solar*	10.38854*** (0.0055)
Hydro → GDP	0.050277 (0.9752)	*GDP → Hydro*	7.624746** (0.0221)
Wind → GDP	4.789664* (0.0912)	*GDP → Wind*	0.467325 (0.7916)

Source: authors' calculations

The implications of a causal relationship between GDP and energy consumption, as well as the reverse relationship of energy consumption to GDP, can provide valuable insights into the interplay between economic activity and energy usage.

When GDP is found to cause changes in energy consumption, it is suggested that economic growth and development drive the demand for energy. This can be attributed to factors such as increased industrial production, urbanization, and higher living standards leading to greater energy needs. This direction of causality implies that GDP growth is a driver of energy consumption. It is relevant to the current study as it explores the impact of GDP growth on energy consumption in Greece.

Conversely, when energy consumption is found to cause changes in GDP, it implies that variations in energy availability, efficiency, or price have a direct influence on economic output. This direction of causality suggests that energy constraints, changes in energy sources, or energy-related policies can shape economic performance. It may be driven by factors such as the share of energy-intensive industries, energy price shocks, or technological advancements affecting energy efficiency.

Conclusions and policy implications

This paper investigates the causal relationship between primary energy consumption and economic growth in Greece in the 1965-2019 period by using annual data. The results of the simple linear regression have showed that there is a positive relationship between primary energy consumption and economic growth. Oil energy consumption has the greatest impact on the economy, followed by coal energy consumption and hydropower. The consumption of renewable sources energy, such as solar and wind, has been observed to have very little effect on the economic growth of the country compared to non-renewable energy sources.

The most important findings of the paper are the results from causality tests. The causality tests have showed that there is a causal relationship between wind energy and GDP, GDP and oil energy consumption, GDP and coal energy consumption, GDP and energy consumption from solar, and GDP and energy consumption from hydro. Therefore, it is observed that, in many cases, there is an effect of GDP on individual forms of energy consumption.

These findings have significant policy implications. These findings carry substantial policy implications, especially in the context of Greece as a member of the European Union. In recent years, Greece, in alignment with the European Union Renewable Energy Directive, has been actively pursuing strategies to bolster the adoption of environmentally sustainable practices. This strategy focuses on energy conservation and utilization of renewable energy sources, which have a recognizably lower environmental footprint. Even though this strategy is followed in accordance with the EU directives, based on the results of this research, it is revealed that, in Greece, energy consumption is mainly sourced in non-renewable energy sources. Despite the gradual increase in the consumption of energy from renewable sources, its effect on the economy has not yet reached the level of non-renewable sources.

Based on these findings, it becomes imperative that more efforts should be made to accelerate the transition towards renewable energy. This may include further incentives and subsidies for renewable energy projects, strengthening research and development initiatives in clean energy technologies and implementing policies that promote the efficient use of renewable energy sources in various sectors (as industry and transportation).

In order to promote sustainable development and reduce dependence on non-renewable energy sources, Greece should consider policy implications for the diversification of energy sources by increasing the proportion of renewable energy sources in the overall energy mix by incentivizing investment in renewable energy infrastructure, implementing energy efficiency measures, developing a favourable regulatory framework that encourages investment in renewable energy sources, launching public awareness campaigns to educate citizens on the benefits of renewable energy and the importance of sustainable practices, promoting an energy saving culture as well as the widespread use of renewable energy in households, businesses and public organizations. In the context of renewable energy sources promotion, more intensive programmes meant to incentivize households and businesses to achieve energy transition could be promoted.

Therefore, for future research, it would be valuable to examine the relationship between renewable and non-renewable energy consumption and economic growth through a comparative study with other countries, particularly in Europe. This analysis will provide a clearer understanding of their respective trajectories and enable more accurate predictions for the future. Conducting such an investigation would be instrumental in shaping future regulatory energy policies in Greece, and in facilitating the country's alignment with the energy targets set by the European Union. By considering both types of energy consumption, policymakers can develop an integrated approach that effectively balances economic growth with environmental sustainability.

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Appendix

Table 5. VAR Model

VAR	GDP	Prima Ener	GDP	Oil	GDP	Gas	GDP	Coal	GDP	Solar	GDP	Hydro	GDP	Wind
LGDP	1.32805***	0.06165	1.48067***	0.53014***	1.62223***	1.71312	1.38661***	-0.51500	1.44562***	-5.52104	1.40996***	-0.17370	1.70074***	1.10475
	(0.13337)	(0.19419)	(0.15163)	(0.19805)	(0.12273)	(1.33931)	(0.11983)	(0.52066)	(0.19102)	(4.42394)	(0.11909)	(0.93569)	(0.10982)	(2.05598)
GDP,	-0.49001***	-0.08939	-0.54454***	-0.61373***	-0.67706***	-1.73699	-0.44195***	0.31578	-0.61314***	10.38368**	-0.46034***	0.64548	-0.82045***	-0.67806
	(0.12679)	(0.18460)	(0.15113)	(0.19739)	(0.11905)	(1.29917)	(0.11187)	(0.48605)	(0.21645)	(5.01300)	(0.11207)	(0.88059)	(0.11200)	(2.09673)
Primar	0.05378	1.23732***												
	(0.10093)	(0.14695)												
Prim	0.02871	-0.27849*												
	(0.10325)	(0.15034)												
Oil_			-0.11960	-0.11528										
			(0.11914)	(0.15562)										
Oil			0.03897	0.04825										
			(0.09124)	(0.11917)										
Gas					-0.00762	0.81060***								
					(0.01426)	(0.15565)								
Gas					0.01470	-0.37253**								
					(0.01409)	(0.15377)								
Coal							0.01596	0.19293						
							(0.03290)	(0.14293)						
Coal							0.02224	0.03466						
							(0.03282)	(0.14258)						
Solar									0.00469	0.11635				
									(0.01158)	(0.26816)				
Solar									-0.01618*	-0.26142				
									(0.00916)	(0.21218)				
Hydro											-0.00344	0.43998***		
											(0.01704)	(0.13392)		
Hydro											-0.00063	-0.14805		
											(0.01650)	(0.12968)		
Wind													0.01183	1.12008***
													(0.00915)	(0.17131)
Wind													-0.00692	-0.19348
													(0.00871)	(0.16297)
Const	0.73892***	0.69862**	0.62698***	0.81644***	0.53907**	0.28491	0.54416***	1.93795**	1.65872***	-47.57600***	0.52326***	0.22696	1.15389***	-3.65327
	(0.21672)	(0.31554)	(0.21481)	(0.28057)	(0.26360)	(2.87661)	(0.19569)	(0.85025)	(0.50508)	(11.69753)	(0.17846)	(1.40219)	(0.37950)	(7.10484)
Obs	53	53	52	52	35	35	52	52	13	13	53	53	31	31

Source: author’s representation