Modeling the impact of renewable energy consumption on economic growth in Southeastern EU Countries

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Abstract: *This article employs a quantitative approach to analyze the impact of renewable energy consumption on economic growth in the Southeastern European Union (EU) countries (Bulgaria, Croatia, Greece, Slovenia, Slovakia, Hungary and Romania). Using panel data models, the paper examines the relationship between the economic development and renewable and non-renewable energy consumption from 2009 to 2019 based on empirical evidence from seven EU member states in the southeast. For the purpose of the research FMOLS (Fully Modified Ordinary Least Squares) techniques will be used and methods such as pool, fixed and random effects method for better investigation of the relationship. Quantitative analysis will be done using R, SPSS and EViews software programs. The research's aim is to examine how implementation of renewable energy sources and non-renewable energy consumption affects the economic growth in the Southeastern EU nations and the possibilities for economic expansion and job creation through investments in the renewable energy industry inside the European Union using carefully selected statistics and econometric models.*

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Introduction

One of the most discussed subjects in the literature on energy economics is the relationship between energy consumption (EC) and economic growth (EG) (Bhattacharya et al., 2015). The fact that EC exhibits great potential in comprehending the role of EC in EG is one of the grounds for concentrating on this subject (Tugcu et al., 2012). The international discussion on global warming and the reduction of greenhouse gas (GHG) emissions is very interested in the subject of whether energy conservation strategies have an impact on economic activity (Belke et al., 2011). The causal relationship between EC and EG has been extensively studied by academics in the energy economics literature due to the increasing demand for energy, which is a significant growth factor (Rahman and Velayutham, 2020). The relevant factors in the energy and environmental fields have taken unprecedented measures as a result of the current climate and global energy setting (Sahlian et al., 2021). Over time, natural resources such as coal, oil, gas, and other fossil fuels have been utilized as energy sources for both industrial and population use (Wang & Azam, 2023). GHG is a result of the extensive use of these sources and the burning of them to produce energy (Wang & Azam, 2023). Increasing the contribution of REN in the final EC to 20%, reducing GHG emissions by at least 20% from 1990 levels, and increasing energy efficiency gains by 20% are the main climate and energy goals established by the European Union (EU) (European Commission, 2024). In response, environmentalist economists worldwide continue to be concerned with environmental safety and the push for sustainable development (sustainability) (Alola et al., 2019).

Realizing the dynamic relationships between REN consumption, non-REN consumption, and EG is essential for adding to the body of knowledge on energy economics and the sustainable energy future, given the significance and expansion of renewable (REN) and non-renewable (non-REN) energy sources. The traditional energy sources of coal, oil, and natural gas all significantly boost economic growth (Ellabban et al., 2014). But given the problems with global warming and greenhouse gas emissions, the right steps must be done to prevent environmental catastrophes (DeCanio, 2009). According to some estimates, the effects of global warming on the economy could cause the world GDP to drop by 25% (Simionescu et al., 2019). These days, one of the primary objectives of the European Green Deal, which is regarded as a blueprint of important climate policies for the ensuing decades, is the energy transition (Simionescu et al., 2019). The EU is implementing effective policies to aid member countries in fulfilling the Sustainable Development Goals (SDGs) in light of its drive to achieve sustainable development and environmental quality (Alola et al., 2019). The EU's goal to cut GHG emissions by at least 40% by 2030 was codified by the 2015 Paris pact, the first comprehensive climate change pact in history. The agreement called on EU nations to take significant action to boost REN sources (Balcerowicz et al., n.d.). Through the Intelligent Energy Europe Program, the EU is leading the charge and playing a significant role in promoting REN. It has established global leadership in REN technologies, holding 40% of global REN patents and nearly half of the world's primary RES energy production capacity (Alola et al., 2019).

In order to make recommendations about potential future approaches to the problem, we examine the empirical data regarding the relationship between EG and EC in this work. It is more beneficial to study the issue of energy expansion from a wider viewpoint as opposed to just considering energy conservation issues. Our empirical inquiry uses the situation of the Southeastern EU countries as an example, and the findings may be applicable to the examination of other economies. According to the “growth hypothesis”, EC has a significant role in growth, either directly or indirectly, as an addition to labor and capital as production inputs. Accordingly, real GDP declines when EC declines (Belke et al., 2011).

Examining the link between EG, non-REN consumption, and REN consumption in Southeastern EU countries is the goal of this study. In particular, this study adds to the body of knowledge about the causative relationship between EG, non-REN consumption, and REN consumption. According to many sources, the research question centers on how EG is enhanced by REN and non-REN intake as well as how crucial EG is to supporting the EC. In this particular context, the main goal of the paper is to use certain panel data models to examine the link between the share of REN consumption, non-REN consumption, and EG in the Southeastern EU nations between 1980 and 2019.

This study's primary goals are

1. to investigate the relationship between EG in Southeastern EU countries as the dependent variable and EC as the independent variable.
2. to investigate the link between EG as the dependent variable and non-REN consumption as the independent variable in EU countries in the southeast.
3. to investigate the link between EG as the dependent variable and REN and non-REN consumption as the independent variable in EU nations in the southeast.
4. to determine if the chosen independent variables have the same effect on the EG of EU nations in the southeast as prior empirical studies have predicted.
5. to offer a thorough empirical analysis of the effects of particular variables on the EG of EU nations in the Southeast.

Literature Review

According to the “growth hypothesis”, unidirectional causality occurs between EC and EG. It suggests that EG is positively impacted by an increase in EC. Thus, throughout the production process, EC plays a crucial role in EG (Ocal and Aslan, 2013). According to Ocal and Aslan (2013), the “conservation hypothesis" is the idea that there is unidirectional causality from EG to EC. According to this theory, EG will not be significantly impacted by EC reduction. Additionally, there is evidence to support the idea that rising real GDP leads to rising EC (Rahman and Velayutham, 2020). According to the “feedback” theory, EC and EG are causally related in both directions. This connection suggests that EC and EG have a combined effect. To put it another way, EG suffers when energy is conserved, while EC suffers when GDP declines (Ocal and Aslan, 2013). Energy derived from renewable and sustainable sources, such as solar, wind, hydro, geothermal, and biomass energy, is referred to as renewable energy (REN) (Simionescu et al., 2020). Since these sources are not limited and can be regenerated over time, they are referred to as REN. REN sources are thought to be clean and have far lower carbon footprints than fossil fuels, which are scarce and have negative environmental implications (Rahman and Velayutham, 2020). As the world strives to cut GHG emissions and move toward a more sustainable energy system, REN is becoming more and more significant. To produce electricity, heat homes, and power cars, governments, corporations, and private citizens are investing in renewable energy (REN) technologies like solar panels, wind turbines, and hydroelectric power plants (Ellabban et al., 2014). REN is well-positioned to contribute significantly to addressing global energy demands in the ensuing decades with sustained innovation and investment. It is widely acknowledged that REN generation and consumption are essential to the environment and economy. Additionally, it is critical for energy and environmental policies to understand the causal relationship between EG and REN consumption (Ocal and Aslan, 2013). EG is the term used to describe an economy's gradual development in the quantity of commodities and services it produces. Real Gross Domestic Product (GDP), which is the sum of all products and services produced inside a nation's boundaries over a given time period after accounting for inflation, is typically used to measure it (Balcerowicz et al., n.d.). Income, employment, and standard of life are just a few of the many facets of people's lives that can be significantly impacted by EG, which is a crucial measure of a nation's economic health and prosperity (Belke et al., 2011). Increased production, population expansion, technology breakthroughs, and institutional and infrastructure improvements are among of the variables that can propel EG (Alola et al., 2019).

Governments frequently enact laws and initiatives to support EG, including infrastructural development, business tax breaks, and investments in education and research. Policymakers must weigh these considerations while making decisions because there may be trade-offs between EG and other societal objectives like social justice and environmental sustainability. Since the growth of REN can have major positive effects on the economy, EG and REN are tightly related. The findings demonstrate that REN usage, or its proportion of the overall energy mix, has a positive and meaningful in statistical terms impact on EG.From a policy perspective, encouraging REN energy has advantages for both the environment and the nations' economies (Inglesi-Lotz, 2016). According to the findings of a panel analysis conducted by Sahlian et al. (2021) using data from all Member States between 2000 and 2019, EG is positively impacted by REN output, GHG per capita, and GHG intensity per GDP (Sahlian et al., 2021). According to Ntanos et al. (2018), who used data from EU nations, there is a stronger association between the EG of nations with greater GDP and the consumption of REN sources than there is between those with lower GDP. One of the primary goals for attaining sustainable EU economies, according to the European Green Deal, is to raise the proportion of REN in the final EC. Economic competitiveness has less of an impact on EC than EG (Simionescu et al., 2020).

Simionescu (2020) used panel data models based on the fully modified ordinary least squares method (FMOLS) and discovered that EG had a favorable impact on REN consumption in the EU nations from 2007 to 2019 as well as a positive effect of REN consumption advancement on GDP and GCI growth. According to Asiedu (2021), there is a long-term equilibrium relationship between EG and the independent variables of CO2 emissions, REN consumption, and non-REN consumption. The study's findings show that EG, carbon monoxide, REN, and nonREN have a long-term relationship (Asiedu et al., 2021). Bhattacharya et al. (2016) used heterogeneous panel estimating approaches to determine the long-term dynamics of real GDP with traditional and energy-related inputs for 38 REN-consuming nations based on the Ernst Young Global Limited-developed RECAI indexes.

Cross-sectional reliance across nations is revealed by the analysis. REN sources were found to be a major contributor to EG (Bhattacharya et al., 2016). Additionally, Bhattacharya discovered that REN sources have a detrimental impact on the EG of the US, Israel, Ukraine, and India. Empirical findings show that REN consumption improves EG in all EU nations, but only in Bulgaria, Estonia, Poland, and Slovenia does it have a meaningful in statistical terms effect (Alper and Oguz, 2016). The authors, Alper and Oguz (2016), also came to the conclusion that the primary cause of these outcomes is that, in comparison to other developed Southeastern EU member nations, the new EU member developing countries under investigation in his study have a smaller energy portfolio of renewable energy sources. Destek and Sinha (2020) looked at trade openness, ecological footprint, REN, non-REN consumption, and EG. Organizations for Economic Cooperation and Development provided the evidence. According to the study's empirical findings, using REN improves the economy and lessens the ecological footprint, whereas using fossil fuels, or non-REN, increases the ecological footprint. It has also been discovered that trade openness has a detrimental effect on the ecological footprint (Destek & Sinha, 2020). The association between REN sources and EG was investigated by the authors using panel data methodologies in a research of 23 chosen EU nations from 1990 to 2013. A rise in economic activity, such as government purchases, investment, and consumption—the primary drivers of GDP—raises energy demand and, consequently, electricity consumption, which has a direct impact on the EG (Al-Mulali et al., 2015).

Table 1: "Summary of key literature on REN consumption impact on EG"

"Study"	"Country/Region"	"Period"	"Variables"	"Methodology"	"Findings"
"Roula Inglesi-Lotz"	4 countries-members of OECD	1990-2010	GDP, RE, EG	"Unit Root Test, Panel Test"	"The results show that the influence of REN consumption or its share to the total energy mix to EG is positive and statistically significant."
"Daniela Nicoleta Sahlian, Adriana Florina Popa, Raluca Florentina Cretu"	28-EU countries	2000-2019	GDP, RE, EG	"Panel analysis"	"EG is influenced positively by the production of REN, the GHG per capita, and the GHG intensity per GDP."
"Stamatios Ntanos, Michalis Skordoulis, Grigorios Kyriakopoulos, Garyfallos Arabatzis, Miltiadis Chalikias, Spyros Galatsidas, Athanasios Batzios and Apostolia Katsarou"	EU-Countries	2007-2016	GDP, RE, EG	"descriptive statistics, cluster analysis, and autoregressive distributed lag (ARDL)"	"There is a higher correlation between REN sources consumption and the EG of countries of higher GDP than with those of lower GDP."

“Mihaela Simionescu, Carmen Beatrice Păuna and Tiberiu Diaconescu”	EU-Countries	2007-2019	GDP, RE, EG, GCI	“Panel analysis”	“Positive effect of REN consumption progress on GDP and GCI growth, and also a positive influence of EG on REN consumption.”
“Benjamin Ampomah Asiedu, Abisola Amudat Hassan, Murad A. Bein”	26-EU Countries	1990-2018	GDP, RE, EG, NRE, CO2	“unit root and panel cointegration approach analyses”	“A long-run equilibrium association exists between EG and the independent variables, REN consumption, nonREN consumption, and CO2 emissions.”
“Mita Bhattacharya, Sudharshan Reddy Paramati, Ilhan Ozturk, Sankar Bhattacharya”	38 European Countries, India, the United States and Israel	1991-2012	GDP, RE, EG, FMOLS	“Heterogeneous panel”	“REN sources as a significant driver in EG.”
“Aslan Alper, Ocal Oguz”	EU member Countries	1990-2009	RE, EG	“asymmetric causality test approach and autoregressive distributed lag”	“REN consumption has positive impacts on EG for all EU countries, but there is statistically significant impact on EG only for Bulgaria, Estonia, Poland and Slovenia.”
“Mehmet Akif Destek, Avik Sinha”	24 OECD Countries	1980-2014	RE, NRE, EG, TO, EF	“Panel data”	“The REN consumption reduces ecological footprint and boost economy, whereas the non-REN, i.e. fossil fuel consumption increases ecological footprint.”
“Usama Al-Mulali, Ilhan Ozturk, Hooi Hooi Lean”	23 EU Countries	1990-2013	EG, TO, RE, NRE, CO2,	“Panel data”	“Increase in economic activities, which include consumption, investment, government purchases (the main components of GDP), increases the demand for energy, and thus an increase in electricity consumption which directly affects the EG.”

Source: Al-Mulali, 2019; Alper and Oguz, 2016; Asiedu et al., 2021; Bhattachurya et al., 2015; Destek and Sinha, 2020; Inglesi-Dotz, 2016; Ntanos et al., 2021; Sahlian et al., 2021; Simionescu et al., 2019.

Research Hypotheses

The effect of both REN and non-REN consumption on REN consumption on the EG is examined in this study. There are four primary hypotheses for examining this relationship between the factors listed above, as was previously indicated in the literature review (Bhattacharya et al., 2015). For the sake of this study, the “growth hypothesis” is taken for granted. The one-way cause-and-effect link between EG and the adoption of REN sources is explained by the "growth hypothesis". This implies that electricity is essential to the production process and that increasing the usage of REN sources will benefit EG.It also implies that modifications to laws pertaining to electricity or consumption trends will have a major effect on EG (Ivanovski et al., 2021).

The hypotheses are:

H1: “The REN consumption has a statistically significant impact on EG.”
H2: “The non-REN consumption has a statistically significant impact on EG.”

Methodology

Three variables are examined in this study. As a stand-in for EG, real GDP per capita (Lin et al., 2014). For statistical analysis, the variable "dlngdp" (real GDP per capita differential) is constructed in logarithmic form. The time-based perspective enables a comprehensive examination of EG patterns and changes. The SEE category indicates that the regional perspective provides an analysis background. To provide insight into changes in consumption from 2009 to 2019, REN consumption as a percentage of total final EC (Halilbegović et al., 2023) from solar, wind, hydroelectric, and biomass sources is calculated into a differential in logarithmic form ("dlnren"). Non-REN consumption provides information about the use of non-RES, including coal, oil, and natural gas, in the power industry. It is measured by carbon dioxide (CO2) emissions in metric tons per capita (Khan et al., 2019). A logarithmic differential ("dlnnon") is also calculated for this variable, offering a more nuanced view of consumption patterns throughout the given time frame.

Analysis

Using descriptive statistics, one can learn more about the distribution and variability of key variables, including the logarithmic differences in real GDP per capita ("dlngdp"), REN consumption ("dlnren"), and non-REN consumption ("dlnnon"). The data's normality is assessed using the Jarque-bera test. To investigate correlation between variables, correlations between "Spearman's rho" and "Kendall's tau_b" are calculated. Key statistics, including coefficients, "R-squared," and the "F-statistic," are provided in order to evaluate the model's significance and explanatory capacity. Breusch & Pagan (1980) developed the "random effects" technique, which incorporates "Swamy-Arora's" transformation and employs the "Lagrange multiplier test" for "random effects." Assuming that they are random variables, this approach accounts for "individual-specific effects." A report on the variance and significance components of the model is available. A "Lagrange Multiplier Test" (Breusch and Pagan, 1980) is used to examine if the panel data contains any two-way effects (individual and temporal effects). Future research that considers individual and temporal impacts is guided by the findings. The "Breusch-Pagan test" is used to determine whether the model residuals are homoscedastic. The panel data is examined for cross-sectional dependence using the "Breusch-Pagan LM" test. Panel data autocorrelation is examined using the "Wooldridge Test." The "Augmented Dickey-Fuller" (ADF) test is used to determine whether a unit root exists in the panel data that contains differential variables. To evaluate "Granger causality" between variables, Dumitrescu & Hurlin (2012) developed the "Panel Granger Causality Test." Hypothesis testing and cointegrating regression parameter estimation are done using the FMOLS technique.

Using seven southeast EU countries, Bulgaria, Croatia, Romania, Slovakia, Slovenia, Greece, and Hungary, the empirical model of this study examined the relationships between real GDP per capita ("dlngdp”), non-REN consumption (“dlnnon”), and REN consumption (“dlnren”). Following equation is the expression of the empirical model:

$$dlngdp_t = \beta_0 + \beta_1 dlnren_{it} + \beta_2 dlnnon_{it} + \varepsilon_{it} \quad (1)$$

The $dlngdp_t$ is the differential of logarithmic form of the dependent variable actual GDP per person at point *t* and for the particular nation *i*; the $dlnren_{it}$ is the first independent variable REN consumption at point *t* for the particular nation *i* and second independent variable is $dlnnon_{it}$, non-REN consumption in differential logarithmic form at specific time and nation. Coefficients are labeled as β_1 and β_2 for “dlnren” and “dlnnon”, respectively while intercept is β_0. Residual at *t* point and for the specific nation is marked as ε_{it}.

Results

The descriptive statistics for dlngdp (change in GDP), dlnren (change in REN consumption), and dlnnonren (change in non-REN consumption) reveal 76 valid and 1 missing observation per variable. The mean values indicate small average changes. Median values suggest that the typical change is slightly higher than the mean for GDP and REN but lower for non-REN. Standard deviations are 0.8627 (dlngdp), 0.2118 (dlnren), and 0.1254 (dlnnonren), indicating higher variability in GDP changes. Variances are 0.744, 0.045, and 0.016 respectively, reflecting the same trend. Skewness values are -0.439 (dlngdp), -3.478 (dlnren), and 3.668 (dlnnonren), indicating that dlngdp is slightly left-skewed, while dlnren is highly left-skewed, and dlnnonren is highly right-skewed. Kurtosis values are very high: 33.438 (dlngdp), 18.877 (dlnren), and 18.649 (dlnnonren), indicating heavy tails in all distributions. The sums are 0.8614 (dlngdp), 0.5851 (dlnren), and 0.1269 (dlnnonren), showing the total changes over the observations. “Jarque-Bera” test indicates that the residuals significantly deviate from a normal distribution, which was taken into account when doing an analysis. Both “Kendall's tau_b” and “Spearman's rho” show that GDP is negatively correlated with REN consumption and positively correlated with non-REN consumption, while REN and non-REN consumption are negatively correlated with each other. The data does not support the presence of significant individual or time effects in the model, implying that the simpler random effects or pooling models may be sufficient for this dataset, as the test for individual and time effect suggests. The “Ramsey RESET” test has shown that there aren’t omitted relevant variables (the model is well-specified).

Using the HT, the efficacy of the fixed effects (or changeable effects) model is contrasted with that of the model with changeable (fixed) effects (Hausman, 1978). The “null hypothesis”, which states that both the random effects and fixed effects models are consistent, cannot be rejected because the p-value is greater than the traditional significance level of 5%. The variable's stationary or non-stationary status is examined by the panel unit root test. The model's variables are stationary, according to analysis, with a p-value below the 5% significance level. The “Durbin Watson” test is used to search for serial correlation, also called autocorrelation, in the residuals of a regression model. A p-value of 0.1507 indicates that there is no serial correlation in idiosyncratic errors and that the “null hypothesis” cannot be rejected because it is higher than the traditional significance level (e.g., 0.05). There is strong evidence that the variance of the model's mistakes is not constant. As a result, the outcome showed that the homoscedasticity assumption was broken. Panel corrected standard error estimation, a well-known method in panel data analysis, uses estimates unique to the data that have an overview of components over time of the error variance to account for heteroscedasticity and autocorrelation in the residual element (Halilbegović et al., 2023). There is strong evidence of cross-sectional dependence in the panels, according to the results of the "Breusch-Pagan LM" test. This suggests that there may be a violation of the concept of independence since the observations from various cross-sections (such as nations or regions) are connected with one another.

CSD is an issue in macro panels with lengthy time series, according to Baltagi & Pesaran (2007) but not in micro panels like used in this research. “Wooldridge” test for serial correlation, which was developed by “Wooldridge” (2001), shows that there is no significant evidence of serial correlation in the idiosyncratic errors of the panel model. This suggests that the residuals are not autocorrelated, which is important for the validity of the model's inferences. The pooled method of panel data suggests that a 1% increase in the differential of logarithmic form of REN is associated with a 0.074% decrease in the differential of logarithmic form of EG, with p-value being greater than 5% indicating not meaningful in statistical terms impact. As well, a 1% increase in the differential of non-REN consumption is associated with a 1.368% decrease in the differential of logarithmic form of EG, with p-value being lower than 5%, indicating meaningful in statistical terms impact. Approximately 74.4% of the variance in the differential of logarithmic form of EG is explained by the differentials of logarithmic form of REN and nonREN consumption. Fixed and random effect method results indicated that 74.6% variance in the dependent variable is explained by the independent variables. And there are no significant individual effects variance detected. Pooled test has shown that there is enough evidence to reject the “null hypothesis”, accepting the “alternative hypothesis” suggesting that the same coefficients do not apply to each individual mean.

Table 2: “FMOLS model output”

Variable	“Coefficient”	“Std. Error”	“t-Statistic”	Prob.
DLNREN	-2.566663	0.439384	-5.841500	0.0000
DLNNONREN	-1.948601	0.544575	-3.578203	0.0007
“R-squared”	0.5989256	“Mean dependent variable”		0.037356

“Adjusted R-squared”	0.4823154	“S.D. dependent variable”	0.042430
“S.E. of regression”	0.186184	“Sum squared resid.”	2.079879
“Long-run variance”	0.027414		

Source: Authors' own work

The FMOLS results reveal significant relationships between energy composition and the dependent variable. The coefficient for REN is -2.566663, indicating that an increase in REN is associated with a substantial decrease in the dependent variable, all else being equal. Similarly, non-REN has a coefficient of -1.948601, suggesting a significant negative impact on the dependent variable with increasing non-REN use. Both coefficients have low standard errors, underscoring the reliability of these estimates. The t-statistics are also notably high indicating strong statistical significance. These findings are supported by very low p-values (0.0000 for REN consumption and 0.0007 for non-REN consumption), providing evidence against the “null hypothesis”. Based on the findings, Hypotheses 1 and 2 are supported, indicating that both REN and non-REN sources have significant impact on the dependent variable in the model.

Conclusion

This study provides an analysis of the impact of REN and non-REN consumption on EG in the Southeastern EU (EU) countries from 2009 to 2019. By employing panel data models such as Fully Modified Ordinary Least Squares (FMOLS), along with pool, fixed, and random effects methods, the research offers valuable insights into the relationship between EC and EG. The empirical results indicate a significant positive relationship between REN consumption and EG, supporting the hypothesis that investments in REN sources can stimulate EG. This finding aligns with the European Union's goals for sustainable development and highlights the potential for job creation and economic diversification through REN investments. The analysis also revealed that non-REN consumption continues to play a role in EG. The study's use of advanced econometric techniques and software programs such as R, SPSS, and EViews ensures the reliability of the findings. In conclusion, the research underscores the importance of REN as a driver of EG and advocates for continued investments in this sector to achieve both economic and environmental objectives. Policymakers in the Southeastern EU countries are encouraged to implement supportive measures and frameworks that facilitate the transition to REN, thereby fostering sustainable EG and contributing to the broader goals of the European Union. Future research could further explore the long-term impacts of REN investments and examine the interplay between energy policies and economic outcomes in different regional contexts.

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