International Conference "Risk in Contemporary Economy" ISSN-L 2067-0532 ISSN online 2344-5386
XXIIIth Edition, 2023, Galati, Romania,
"Dunarea de Jos" University of Galati, Romania – Faculty of Economics and Business Administration

DOI https://doi.org/10.35219/rce20670532148

Approaches to the Possibilities of Achieving Energy Efficiency through a Dynamic European Regional Model

Monica Laura Zlati
sorici_monica@yahoo.com
Dunarea de Jos University, Galati, Romania
Costinela Fortea
costinela.fortea@yahoo.com
Dunarea de Jos University, Galati, Romania
Valentin Marian Antohi
valentin_antohi@yahoo.com - *Corresponding author*
Dunarea de Jos University, Galati, Romania; Transilvania University, Brasov, Romania
Romeo Victor Ionescu
ionescu_v_romeo@yahoo.com
Dunarea de Jos University, Galati, Romania
Dragos Sebastian Cristea
dragos.cristea@yahoo.com
Dunarea de Jos University, Galati, Romania

The article is written in the current context of the energy crisis triggered by the geopolitical conflict but also by the need for sustainability translated into sustainable development objectives assumed at European level through the Green Deal Pact and the sustainable development agreements with 2030 and 2050 horizon. The objectives of the study are to determine a regional dynamic model of energy efficiency based on the results disseminated in the literature on this topic. The methods used consist of descriptive analytical research of energy sector indicators at European level with the application of the linear regression method to determine the regional dynamic energy efficiency model. The results of the study consist in determining the regional character of energy efficiency and identifying the factors influencing the achievement of this objective at European level by studying the differences at the level of six Member States considered to be representative in terms of their respective levels of economic development, Germany, France, Austria, Greece, Bulgaria and Romania. The results of the study are useful for energy policy makers in reorienting energy development strategies in the current context of the energy crisis.

Keywords: renewable energy, GDP, energy efficiency, sustainable development

JEL Code: Q4, Q01

1. Introduction

The onset of the economic crisis has brought European energy security to the forefront amidst the European Union's dependence on Russian oil and energy imports (prior to the outbreak of the conflict). In this context, the Versailles Declaration of March 2022 was adopted in which European states opted to increase energy security, eliminate hydrocarbon imports from Russia by 2027 and diversify the origin of gas imports. At the same time, the European economy has been oriented towards reducing energy consumption and developing clean, environmentally friendly energy technologies. Other proposed measures include smart investment in the green energy transition, industrial decarbonisation and reducing import dependency by stabilising the energy consumption balance. In the 6 countries analysed, the evolution of gross natural gas consumption has shown a downward trend both by reducing energy consumption in thermal power plants and by increasing the energy efficiency of households, which has led to a reduction of energy consumption in the social sector, while in the industrial sector, as a result of industrial decarbonisation reforms, a significant reduction in consumption has also been achieved (Figure 1).

The most significant reductions were recorded in Germany, where the trend curve of Complete energy balances is determined by the equation: $y = -3854.2x + 336827$, followed by France with a trend curve of the indicator determined by the equation: $y = -3427.9x + 273403$ and Greece $y = -495.92x + 28410$.

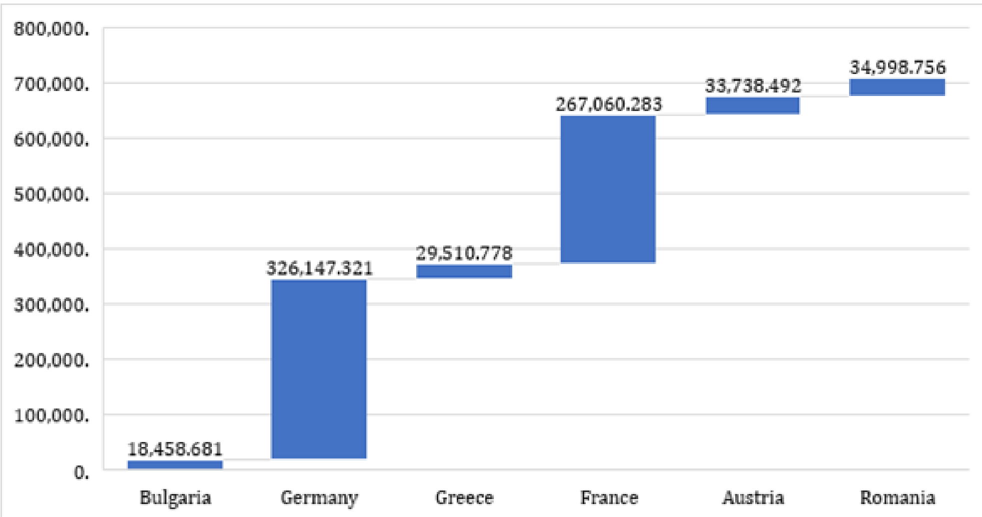

Figure 1. Complete energy balances (Gross available energy) in the 6 countries analysed in 2012-2021

Source: Eurostat, available at https://ec.europa.eu/eurostat/databrowser/view/nrg_bal_c/default/table?lang=en

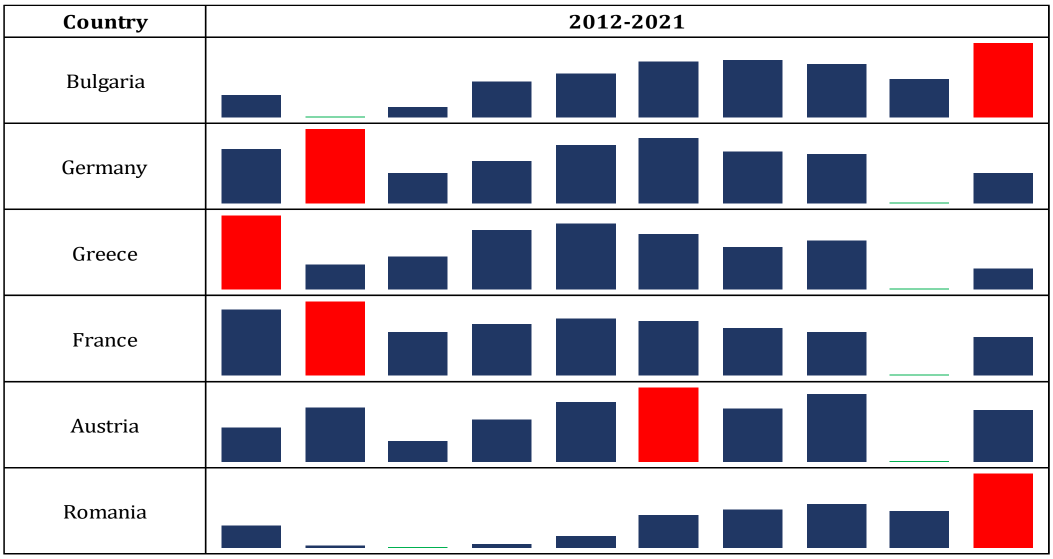

Figure 2. Complete energy balances (Final energy consumption) in the 6 countries analysed in 2012-2021

Source: Eurostat, available at https://ec.europa.eu/eurostat/databrowser/view/nrg_bal_c/default/table?lang=en

Final energy consumption at the level of the 6 countries as reported by Eurostat showed a downward trend in Germany, France, Austria and Greece, while Bulgaria and Romania showed an increase towards the end of the period under review as shown in Figure 2.

In this context, the main objective of the study is to determine the possibilities of achieving energy efficiency from a regional perspective by analysing the historical evolution of the energy balance indicators in relation to the GDP per capita economic deflator at the level of the 6 European Member States, which will be achieved through the following secondary objectives:

O1: Evolution of the concept of energy efficiency in the context of sustainable development in the literature;

O2: Identification of indicators subject to modelling and quantification of their evolution through a consolidated database;

O3: Conceptualisation of the energy efficiency model, its testing and validation;

The study continues with the literature review, definition of the working methodology, presentation of results and discussions and formulation of relevant conclusions.

2. Literature review

The energy crisis triggered in Europe by the Russian-Ukrainian conflict has changed the regional paradigm for energy consumption in a significant way. While until 2019 energy-intensive activities such as agriculture and services, especially transport, were monitored according to a more straightforward European procedure, the current situation driven by a complex mix of macroeconomic influences suggests and points to a much greater opportunity for the closure of some activities in these sectors. At the level of the literature, there are concerns of researchers in the field who, as can be seen from the bibliometric analysis below, have developed and implemented solutions, in particular to achieve the sustainable development objectives and targets set by the Green Deal Pact.

As shown by Akram R. and others (Akram et al., 2021a) a significant aspect of the energy sector during crises is energy efficiency (Akram et al., 2021b; Iram et al., 2020; Mahi et al., 2021). Using a statistical panel data model, the authors (Akram et al., 2021a) correlate economic growth with energy efficiency, capital formation (Danish & Ulucak, 2020; Topcu et al., 2020), energy consumption as a percentage of GDP as well as renewable energy distribution and balance of payments. According to the model it is shown that BRICS countries (Cristea et al., 2022; Pata, 2021; Ren et al., 2022; Sinha et al., 2019; Usman & Makhdum, 2021; Wahab et al., 2022; Zeng & Yue, 2022), including Russia, contribute significantly to maintaining the global energy balance even though energy efficiency indicators maintain a low correlation with economic growth. The 2021 study foresees future risks induced by the weak causal relationship between energy efficiency and sustainable economic growth. A problematic issue reported in the literature is electricity consumption in relation to greenhouse gas emissions, thus (Ahmad & Zhao, 2018) show that a coordinating and correlating relationship can be identified between the level of industrialization, urbanization, level of energy consumption in relation to greenhouse gas emissions and economic growth. This framework is subject to the impact of regional disparities being influenced by industrial expansion, urbanisation and labour market saturation. According to the study, the highest greenhouse gas emissions are specific to highly industrialised areas, with territorial disaggregation's according to primary (agriculture), secondary (manufacturing) and tertiary (services) industrialisation. The same focus on greenhouse gas emissions from the perspective of their reduction effect through investments is made by (Adedoyin et al., 2020; Nepal et al., 2021) which compares energy security with the results set to be implemented in terms of environmental sustainability development.

A meta-analysis conducted through the Web of Science platform and VOSviewer shows that energy security can be approached from the perspective of energy sector development as a viable activity to achieve the optimal level of environmental sustainability (Figure 3).

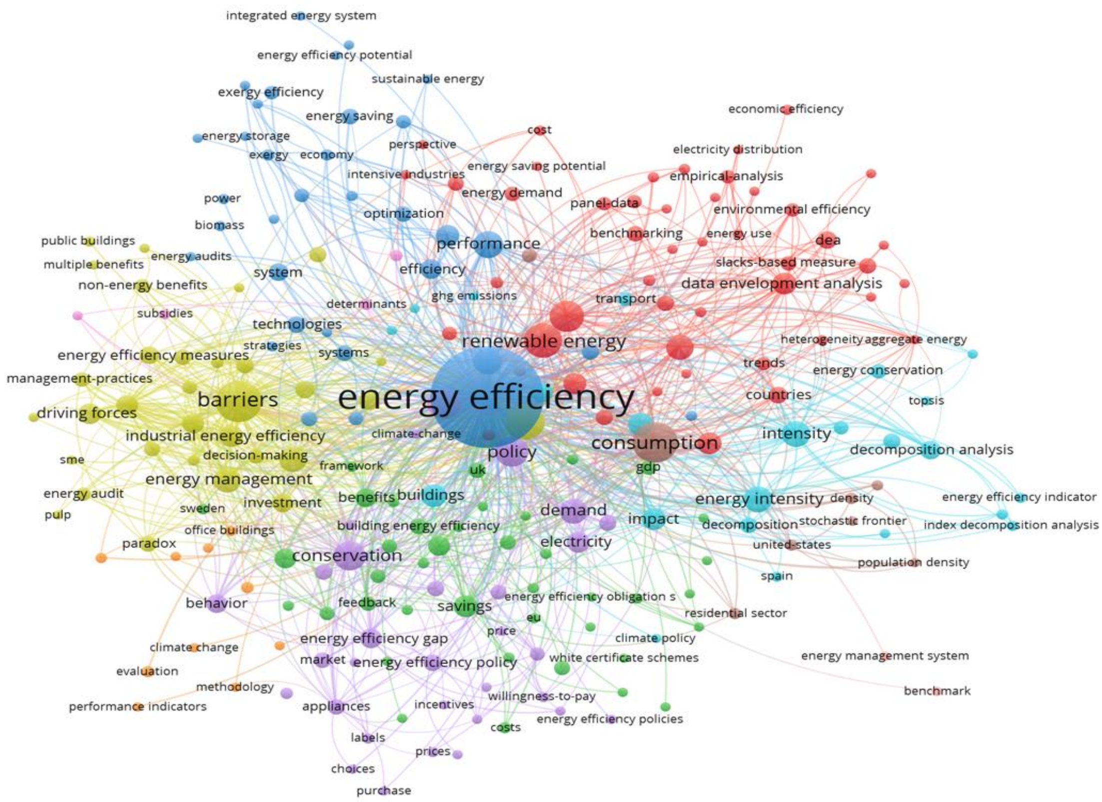

Figure 3. The bibliometric analysis on the energy efficiency
Source: Elaborated by the authors using VOSviewer software

The analysis, based on research of 6200 articles published in the last 5 years, presents 6 development clusters, namely the development of the renewable energy sector, the optimisation of energy consumption, the creation of a reliable conceptual framework for the operation of the energy industry, the implementation of sustainable energy policies, the increase of performance and the limitation of greenhouse gas emissions. The analysis showed the researchers' concern for current energy issues, namely energy security and environmental protection.

Another meta-analysis (Figure 4), covering more than 7500 articles written in the period 2020-2022, focuses on the interrelated aspects of sustainable development and energy efficiency.

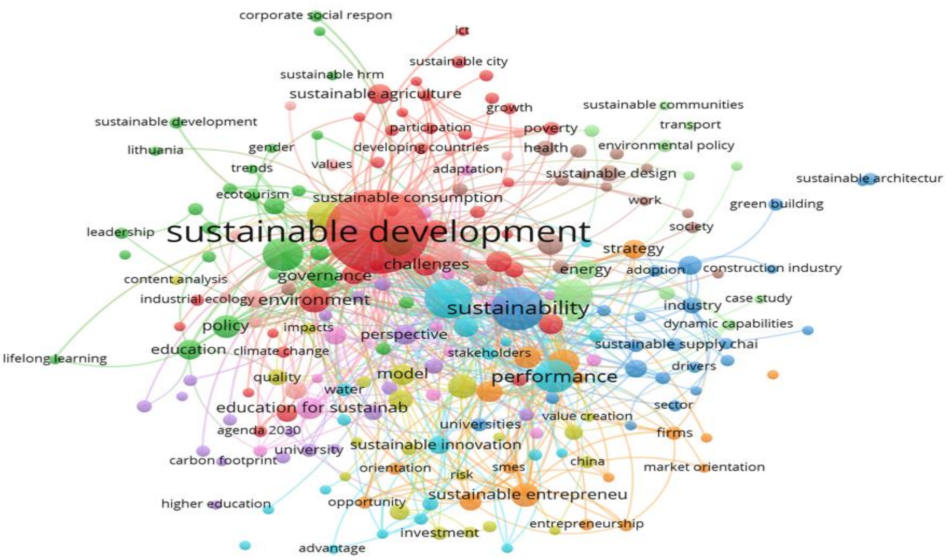

Figure 4. The bibliometric analysis on the sustainable development
Source: Elaborated by the authors using VOSviewer software

Against the backdrop of concerns for sustainable development, the meta-analysis conducted captures 10 clusters of scientific interest that impact sustainable development in relation to energy efficiency (Figure 4).

In the paper Asymmetric effects of energy efficiency and renewable energy on carbon emissions of BRICS economies: evidence from nonlinear panel autoregressive distributed lag model (Akram et al., 2020) the authors present a lagged distribution model demonstrating that energy efficiency and increasing the share of energy consumption from renewable sources (Sharma et al., 2021) are key to improving environmental quality. The authors conclude that investments in R&D and innovation are needed to achieve energy efficiency targets for industries that limit environmental pollution (Khan et al., 2021). Also in this regard (Nathaniel et al., 2021) they analyse the impact of nuclear energy with a focus on diversifying clean energy sources in the energy consumption basket. According to (Ibrahim & Alola, 2020) quantifying renewable energy in the current context of sustainable development is a source of strengthening environmental sustainability. Other authors (Mohsin et al., 2021) show that monitoring greenhouse gas pollution, a modern-day necessity, can help economic policy makers in improving energy strategies and increasing the sustainability of the economy. Another study (Moreau & Vuille, 2018) presents a current solution of decarbonising economic activities and increasing energy security by reducing the level of energy consumption from non-renewable sources in industrial sectors and increasing economic activity in the tertiary sector with an impact on economic sustainability. From another perspective (Nawaz et al., 2021) presents the trilemma association of energy consumption, carbon emission, and economic growth, the solution in this regard proposed by the authors is to increase the investment process and development of technologies in the energy sector. According to (Namahoro et al., 2021) renewable energy consumption contributed to mitigating CO2 emissions, while energy intensity promoted emissions across regions and income levels. The environmental stress assigned by (Zhang et al., 2020) to energy consumption can be analysed through the Environmental Kuznets Curve (Adebayo et al., 2022; Moutinho et al., 2017; Sterpu et al., 2018), the authors believe that increasing consumption from renewable sources can prevent environmental degradation, reduce climate change (Dellink et al., 2017) and improve ecosystem health. The authors propose pollution reduction actions such as monitoring air pollution based on reducing industrial energy consumption, reducing the use of fossil fuels and switching to green fuels (Leal et al., 2019; Li & Lin, 2017; Magazzino et al., 2021; Sohag et al., 2019; Wang et al., 2020) that also improve energy security. According to the authors, energy efficiency is a cost-reducing factor as well as a factor in reducing environmental impacts. Another study (Fu et al., 2021) highlights the dynamic role of energy security, energy equity and environmental sustainability in the dilemma of emission reduction and economic growth and proposes to use the Energy Trilemma Index (ETI) 2018 of the World Energy Council (WEC) to measure, evaluate and assess the energy efficiency of the top ten best-performing countries around the world.

3. Research methodology

The working methodology consists of the identification of energy efficiency indicators in international reporting (databases OECD (OECD, 2022) şi Eurostat (Eurostat, 2022b) followed by the data consolidation technique applied to the selected information, resulting in a homogeneous modelled record over the period 2000-2021 to be modelled using the multiple linear regression method for the following indicators:

- Primary energy supply Total, Toe/1 000 US dollars, 2000 – 2021
- Crude oil production Total, Thousand toe, 2000 – 2021
- Electricity generation Total, Gigawatt-hours, 2000 – 2021
- Final energy consumption in households per capita, 2000-2021
- Real GDP per capita, 2000-2021

Data were collected for the following 6 European countries: Germany, France, Austria, Greece, Bulgaria and Romania. The reason for selecting the group of 6 countries is the significant level of regional disparities in economic and industrial development as well as the level of disparity in the efficiency of the energy industry in the Member States.

The working hypotheses are:

H1: Energy efficiency is directly dependent on the domestic electricity generation capacity of Member States;

H2: The level of regional energy efficiency disparity is influenced by the variability of the Crude oil production indicator in European Member States;

H3: Domestic generation capacity influences the level of energy efficiency in Member States, which is enhanced by the level of economic development indicated by the GDP per capita deflator.

The econometric model is obtained by applying the linear regression model to the records in the consolidated database with the dependent variable Primary energy supply selected. The data were processed using SPSS vs 25 statistical software.

The conceptualized regional dynamic model is presented in the 6 equations below:

$$PrimaryEnergySupply\,(AUT) = -0.0000004 * ElectricityGeneration(AUT) + 0.00001 * CrudeOilProduction(AUT) - 0.0000011 * GDPcap(AUT) + 0.0000427 * FinalEnergyConsHHcap(AUT) + 0.103123 \quad (1)$$

$$PrimaryEnergySupply\,(BGR) = 0.0000001 * ElectricityGeneration(BGR) + 0.0020289 * CrudeOilProduction(BGR) - 0.0000251 * GDPcap(BGR) - 0.0000062 * FinalEnergyConsHHcap(BGR) + 0.2309931 \quad (2)$$

$$PrimaryEnergySupply\,(FRA) = 0.0000002 * ElectricityGeneration(FRA) + 0.0000218 * CrudeOilProduction(FRA) - 0.0000038 * GDPcap(FRA) + 0.0000626 * FinalEnergyConsHHcap(FRA) + 0.0364084 \quad (3)$$

$$PrimaryEnergySupply\,(DEU) = 0.0000001 * ElectricityGeneration(DEU) + 0.000004 * CrudeOilProduction(DEU) - 0.0000036 * GDPcap(DEU) + 0.0000376 * FinalEnergyConsHHcap(DEU) + 0.1163441 \quad (4)$$

$$PrimaryEnergySupply\,(GRC) = 0.0000012 * ElectricityGeneration(GRC) + 0.0000556 * CrudeOilProduction(GRC) - 0.0000026 * GDPcap(GRC) + 0.000054 * FinalEnergyConsHHcap(GRC) + 0.0393287 \quad (5)$$

$$PrimaryEnergySupply\,(ROU) = -0.0000001 * ElectricityGeneration(ROU) + 0.000023 * CrudeOilProduction(ROU) - 0.0000057 * GDPcap(ROU) + 0.000108 * FinalEnergyConsHHcap(ROU) + 0.0010165 \quad (6)$$

From the equations presented it can be seen that in general the regression coefficients are positive for Crude Oil Production, Final energy consumption in households per capita and Electricity generation while for GDP per capita the coefficients are negative.

Table 1 shows the summary of the model both in terms of the regional component and in relation to the unselected regional components, the overall level being above 60%, statistically significant correlation, for Austria, Bulgaria, France, Germany and Romania and below 60% for Greece. There were 4 highly statistically significant correlations with an index of determination above 93% for Bulgaria, France, Germany and Romania, while in Greece and Austria the level of significance is much lower, which confirms hypothesis 1 of the study (Energy efficiency is directly dependent on domestic electricity generation capacity in the Member States).

Table 1. Model Summary

Model	$R^{a,b,c}$		R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson Statistic	
	Location selected	Location unselected				R Square Change	F Change	df1	df2	Sig. F Change	Location selected	Location unselected
AUT	0.822	0.277	0.676	0.600	0.003424	0.676	8.866	4	17	0.000	0.655	0.033
BGR	0.973	0.487	0.946	0.933	0.009691	0.946	74.588	4	17	0.000	1.676	0.073
FRA	0.975	0.101	0.952	0.940	0.002553	0.952	83.551	4	17	0.000	1.983	0.075
DEU	0.993	0.528	0.986	0.983	0.001550	0.986	301.940	4	17	0.000	1.465	0.041
GRC	0.760	0.000	0.578	0.478	0.004308	0.578	5.810	4	17	0.004	0.938	0.034

ROU	0.989	0.643	0.978	0.972	0.004755	0.978	185.580	4	17	0.000	1.509	0.005
a. Predictors: (Constant), FinalEnergyConsHHcap, CrudeOilProduction, ElectricityGeneration, GDPcap												
b. Unless noted otherwise, statistics are based only on cases for which Location ={AUT, or BGR, or FRA, or DEU, or GRC, or ROU}												
c. Dependent Variable: PrimaryEnergySupply												

Source: Authors' calculations using SPSS v 25

From the data presented in Table 1 it appears that there is a leftward skewness of the regression distributions for all the Member States analysed except France, which confirms working hypothesis 2 (the level of regional disparity in energy efficiency is influenced by the variability of the Crude oil production indicator in the European Member States). With regard to the value of the F function, it can be seen that domestic generation capacity influences the level of energy efficiency in the Member States, which is enhanced by the level of economic development indicated by the GDP per capita deflator (working hypothesis 3).

Table 2 shows the Anova analysis confirming the validity of the models by means of the distribution of degrees of freedom and the value of the Sig coefficients assigned to the F function, which is lower than the selected threshold of error representation, allowing in all cases to reject the null hypothesis and maintain the alternative hypothesis.

Table 2. ANOVA

Model[a,b]		Sum of Squares	df	Mean Square	F	Sig. [c]	Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	AUT	0.000	4	0.000	8.866	0.000	DEU	0.003	4	0.001	301.940	0.000[c]
Residual		0.000	17	0.000				0.000	17	0.000		
Total		0.001	21					0.003	21			
Regression	BGR	0.028	4	0.007	74.588	0.000[c]	GRC	0.000	4	0.000	5.810	0.004[c]
Residual		0.002	17	0.000				0.000	17	0.000		
Total		0.030	21					0.001	21			
Regression	FRA	0.002	4	0.001	83.551	0.000[c]	ROU	0.017	4	0.004	185.580	0.000[c]
Residual		0.000	17	0.000				0.000	17	0.000		
Total		0.002	21					0.017	21			
a. Dependent Variable: PrimaryEnergySupply												
b. Selecting only cases for which Location ={AUT, or BGR, or FRA, or DEU, or GRC, or ROU}												
c. Predictors: (Constant), FinalEnergyConsHHcap, ElectricityGeneration, CrudeOilProduction, GDPcap												

Source: Authors' calculations using SPSS v 25

The Anova table shows that the model is representative of the phenomenon studied and that the possibilities of achieving energy efficiency depend both on the structure of the energy balance in the Member State and its economic capacity.

4. Results and Discussion

The analysis of energy efficiency based on the projected dynamic regional model shows that the regressors vary differently depending on the level of regional development but also on the energy autonomy of each country (Table 3).

Table 3. Pearson correlation coefficients of variable dependence with model regressors

	Regressors	AUT	BGR	FRA	DEU	GRC	ROU
Pearson Correlation - PrimaryEnergySupply	ElectricityGeneration	-0.666	-0.376	0.020	-0.377	0.292	-0.628
	CrudeOilProduction	0.661	0.843	0.876	0.948	0.356	0.983
	GDPcap	-0.789	-0.960	-0.833	-0.970	-0.008	-0.964
	FinalEnergyConsHHcap	0.363	-0.855	0.787	0.839	0.382	-0.700

Source: Authors' calculations using SPSS v 25

Thus, Austria, Bulgaria, Germany and Romania have a negative correlation of electricity supply in the primary sector to power generation capacity. The most significant negative correlations are found for Austria and Romania, at the opposite pole the weakest correlation is found for France and Bulgaria. This is in line with the official statistic that Germany had the highest level of net electricity generation in 2020 among EU Member States, accounting for 20.5%. Between 2019 and 2020, 16 EU Member States reported a decrease in their level of electricity generation in 2020, with some of the largest decreases recorded in Bulgaria (-7.7%) (Eurostat, 2022a).

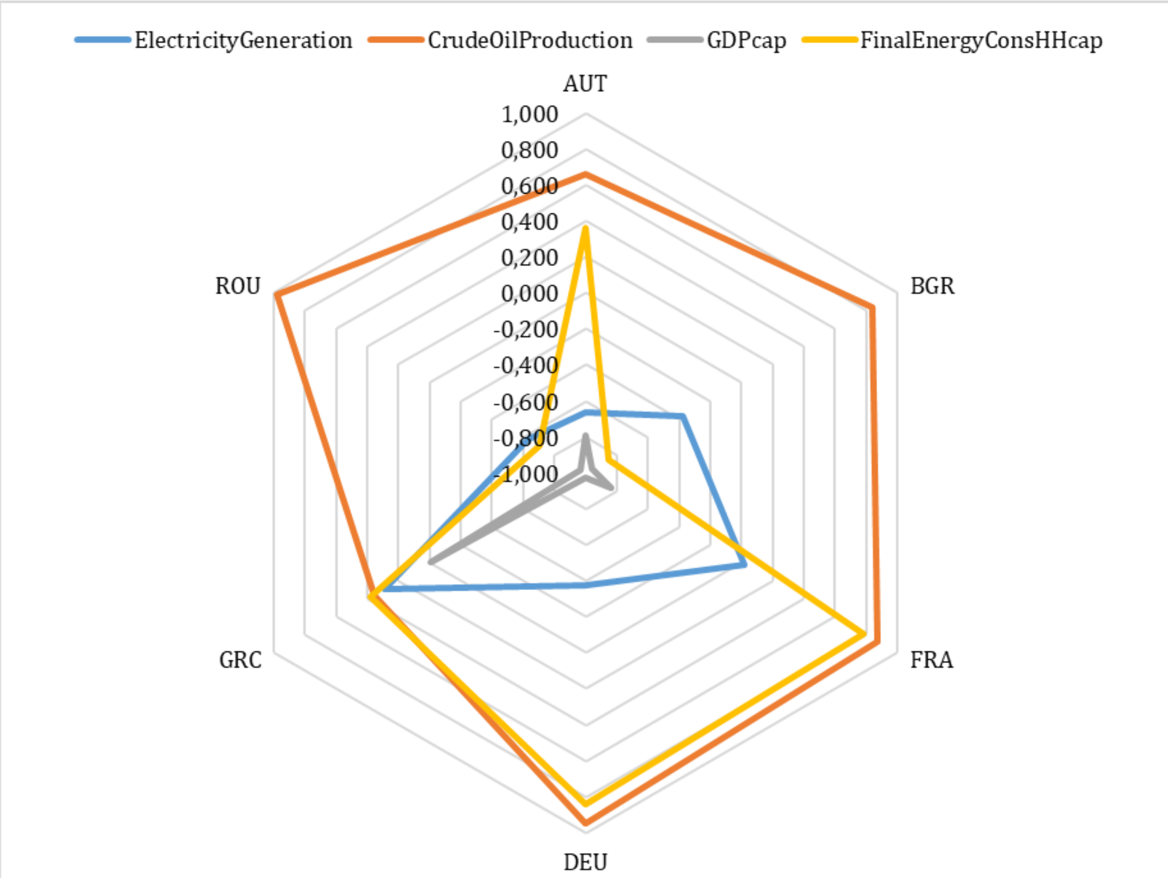

Figure 5. Graphical representation of correlation differences of regional models according to the variation of Pearson coefficients

Source: Elaborated by the authors

Figure 5 shows the regional disparities of the proposed model, demonstrating that in relation to regional coordination energy efficiency is a desideratum on which the European Union still needs to take many steps to achieve a coherent energy efficiency function throughout the European area.

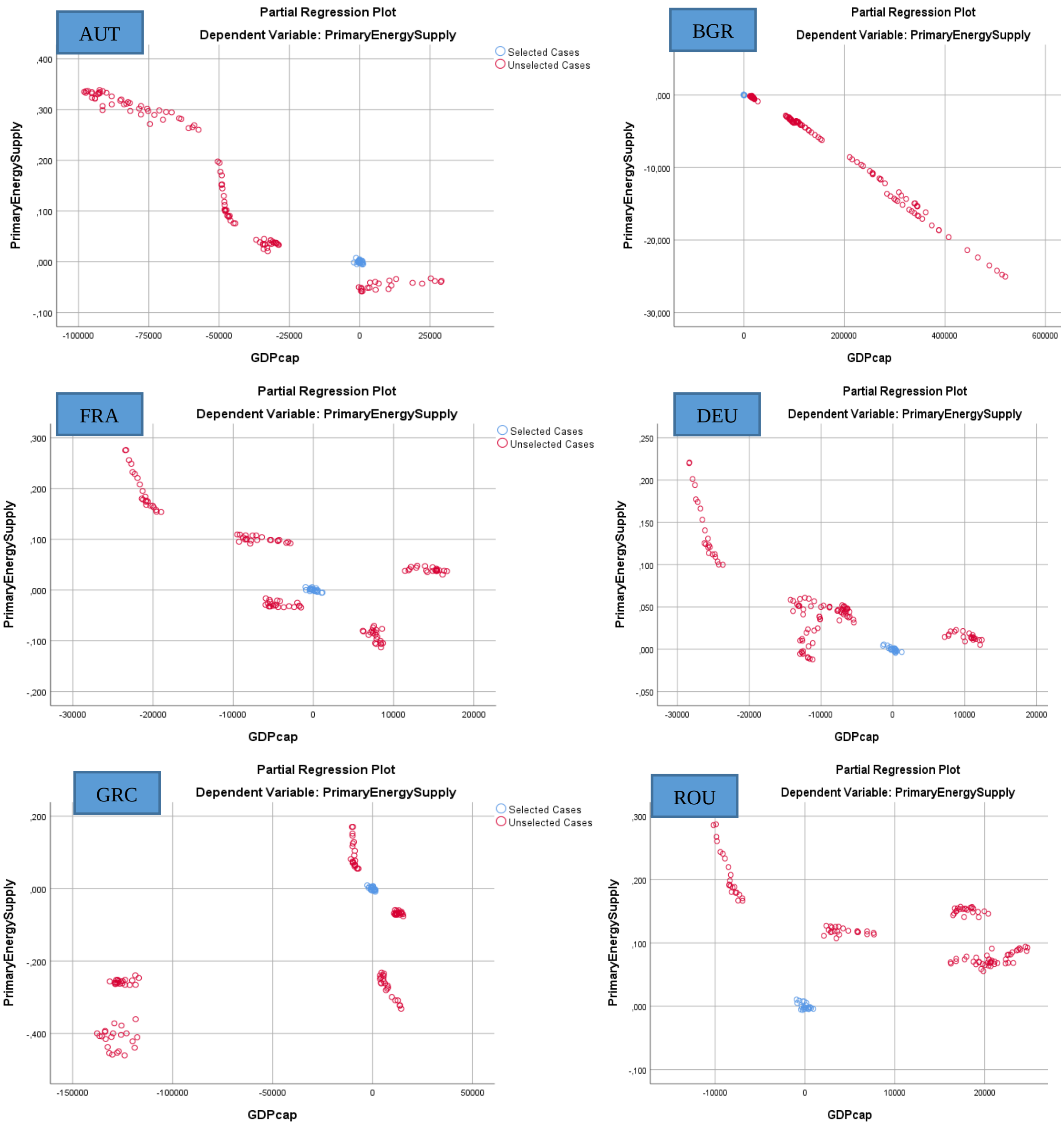

Figure 6. Distribution of partial correlations for the model dependent variable indicator and GDP regressor

Source: Authors' calculations using SPSS v 25

Figure 6 shows the distribution of partial correlations of the dependent variable with the level of regional welfare, which is favourable to the developed economies, Austria, France and Germany, the weakest correlation, as shown in Table 1, being that of Bulgaria, which does not record the minimum energy efficiency parameters.

5. Conclusion

The study is a topical one based on the needs of European economies for energy security and sustainability, configuring possible development directions based on regional disparities in achieving this goal. The objectives of the study have been achieved, as the authors have carried out an extensive literature survey (more than 13,700 articles published in the last 5 years) which has shown that the research orientation on energy efficiency is in line with the principles of sustainable development, increasing the share of renewable energy sources in the final consumption of the population as well as identifying methods to achieve energy efficiency and alignment with the EU targets set by the Green Deal Pact. On the basis of the literature research, the working hypotheses were established and demonstrated during the testing and validation of the proposed dynamic regional model, resulting in the fact that the factors that generate the direct dependence of energy efficiency on energy policies are the generation capacity, the production capacity in the primary sector and the level of economic development, with significant regional disparities in energy efficiency in relation to these factors. The model was implemented on the basis of statistical data from 200-2021 collected for the main statistical indicators assessing the energy status in 6 European Member States Germany, France, Bulgaria, Austria, Greece and Romania. The results of the study are useful for energy policy makers to reorient the energy development strategy in the current context of energy crisis. The limitations of the study lie in the relatively small number of indicators analysed and the limitation of the regional dimension to the six countries analysed, and the authors propose to extend these research directions in a new study.

Acknowledgement: This research was conducted within the internal research grant RF 1821/31.03.2023 provided by "Dunarea de Jos" University of Galati.

References:

Adebayo, T. S., Rjoub, H., Akadiri, S. Saint, Oladipupo, S. D., Sharif, A., & Adeshola, I. (2022). The role of economic complexity in the environmental Kuznets curve of MINT economies: evidence from method of moments quantile regression. *Environmental Science and Pollution Research*, *29*(16), 24248–24260. https://doi.org/10.1007/s11356-021-17524-0

Adedoyin, F. F., Bekun, F. V., Driha, O. M., & Balsalobre-Lorente, D. (2020). The effects of air transportation, energy, ICT and FDI on economic growth in the industry 4.0 era: Evidence from the United States. *Technological Forecasting and Social Change*, *160*(September), 1–10. https://doi.org/10.1016/j.techfore.2020.120297

Ahmad, M., & Zhao, Z.-Y. (2018). Empirics on linkages among industrialization, urbanization, energy consumption, CO2 emissions and economic growth: a heterogeneous panel study of China. *Environmental Science and Pollution Research*, *25*(30), 30617–30632. https://doi.org/10.1007/s11356-018-3054-3

Akram, R., Chen, F., Khalid, F., Huang, G., & Irfan, M. (2021a). Heterogeneous effects of energy efficiency and renewable energy on economic growth of BRICS countries: A fixed effect panel quantile regression analysis. *Energy*, *215*, 1–11. https://doi.org/https://doi.org/10.1016/j.energy.2020.119019

Akram, R., Chen, F., Khalid, F., Huang, G., & Irfan, M. (2021b). Heterogeneous effects of energy efficiency and renewable energy on economic growth of BRICS countries: A fixed effect panel quantile regression analysis. *Energy*, *215*, 1–11. https://doi.org/10.1016/j.energy.2020.119019

Akram, R., Majeed, M. T., Fareed, Z., Khalid, F., & Ye, C. (2020). Asymmetric effects of energy efficiency and renewable energy on carbon emissions of BRICS economies: evidence from nonlinear panel autoregressive distributed lag model. *Environmental Science and Pollution Research*, *27*(15), 18254–18268. https://doi.org/10.1007/s11356-020-08353-8

Cristea, D. S., Zamfir, C. G., Simionov, I. A., Fortea, C., Ionescu, R. V., Zlati, M. L., Antohi, V. M., Munteanu, D., & Petrea, S. M. (2022). Renewable energy strategy analysis in relation to environmental pollution for BRICS, G7, and EU countries by using a machine learning framework and panel data analysis. *Frontiers in Environmental Science*, *10*. https://doi.org/10.3389/fenvs.2022.1005806

Danish, & Ulucak, R. (2020). How do environmental technologies affect green growth? Evidence from BRICS economies. *Science of The Total Environment*, *712*, 1–7. https://doi.org/https://doi.org/10.1016/j.scitotenv.2020.136504

Dellink, R., Chateau, J., Lanzi, E., & Magné, B. (2017). Long-term economic growth projections in the Shared Socioeconomic Pathways. *Global Environmental Change*, *42*, 200–214. https://doi.org/10.1016/j.gloenvcha.2015.06.004

Eurostat. (2022a). *Electricity production, consumption and market overview*. Europa.Eu. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Electricity_production,_consumption_and_market_overview#Market_shares

Eurostat. (2022b). *Eurostat*. Europa.Eu. https://ec.europa.eu/eurostat/databrowser/explore/all/all_themes?lang=en&display=list&sort=category

Fu, F. Y., Alharthi, M., Bhatti, Z., Sun, L., Rasul, F., Hanif, I., & Iqbal, W. (2021). The dynamic role of energy security, energy equity and environmental sustainability in the dilemma of emission reduction and economic growth. *Journal of Environmental Management*, *280*(November 2020), 1–9. https://doi.org/10.1016/j.jenvman.2020.111828

Ibrahim, M. D., & Alola, A. A. (2020). Integrated analysis of energy-economic development-environmental sustainability nexus: Case study of MENA countries. *Science of the Total Environment*, *737*, 1–11. https://doi.org/10.1016/j.scitotenv.2020.139768

Iram, R., Zhang, J., Erdogan, S., Abbas, Q., & Mohsin, M. (2020). Economics of energy and environmental efficiency: evidence from OECD countries. *Environmental Science and Pollution Research*, *27*(4), 3858–3870. https://doi.org/10.1007/s11356-019-07020-x

Khan, A., Chenggang, Y., Hussain, J., & Kui, Z. (2021). Impact of technological innovation, financial development and foreign direct investment on renewable energy, non-renewable energy and the environment in belt & Road Initiative countries. *Renewable Energy*, *171*, 479–491. https://doi.org/10.1016/j.renene.2021.02.075

Leal, P. A., Marques, A. C., & Fuinhas, J. A. (2019). Decoupling economic growth from GHG emissions: Decomposition analysis by sectoral factors for Australia. *Economic Analysis and Policy*, *62*, 12–26. https://doi.org/https://doi.org/10.1016/j.eap.2018.11.003

Li, K., & Lin, B. (2017). Economic growth model, structural transformation, and green productivity in China. *Applied Energy*, *187*, 489–500. https://doi.org/10.1016/j.apenergy.2016.11.075

Magazzino, C., Porrini, D., Fusco, G., & Schneider, N. (2021). Investigating the link among ICT, electricity consumption, air pollution, and economic growth in EU countries. *Energy Sources, Part B: Economics, Planning, and Policy*, *16*(11–12), 976–998. https://doi.org/10.1080/15567249.2020.1868622

Mahi, M., Ismail, I., Phoong, S. W., & Isa, C. R. (2021). Mapping trends and knowledge structure of energy efficiency research: what we know and where we are going. *Environmental Science and Pollution Research*, *28*(27), 35327–35345. https://doi.org/10.1007/s11356-021-14367-7

Mohsin, M., Kamran, H. W., Atif Nawaz, M., Sajjad Hussain, M., & Dahri, A. S. (2021). Assessing the impact of transition from nonrenewable to renewable energy consumption on economic growth-environmental nexus from developing Asian economies. *Journal of Environmental Management*, *284*, 1–8. https://doi.org/https://doi.org/10.1016/j.jenvman.2021.111999

Moreau, V., & Vuille, F. (2018). Decoupling energy use and economic growth: Counter evidence from structural effects and embodied energy in trade. *Applied Energy*, *215*(September 2017), 54–62. https://doi.org/10.1016/j.apenergy.2018.01.044

Moutinho, V., Varum, C., & Madaleno, M. (2017). How economic growth affects emissions? An investigation of the environmental Kuznets curve in Portuguese and Spanish economic activity sectors. *Energy Policy*, *106*(October 2016), 326–344. https://doi.org/10.1016/j.enpol.2017.03.069

Namahoro, J. P., Wu, Q., Zhou, N., & Xue, S. (2021). Impact of energy intensity, renewable energy, and economic growth on CO2 emissions: Evidence from Africa across regions and income levels. *Renewable and Sustainable Energy Reviews*, *147*, 1–13. https://doi.org/https://doi.org/10.1016/j.rser.2021.111233

Nathaniel, S. P., Alam, M. S., Murshed, M., Mahmood, H., & Ahmad, P. (2021). The roles of nuclear energy, renewable energy, and economic growth in the abatement of carbon dioxide emissions in the G7 countries. *Environmental Science and Pollution Research*, *28*(35), 47957–47972. https://doi.org/10.1007/s11356-021-13728-6

Nawaz, M. A., Hussain, M. S., Kamran, H. W., Ehsanullah, S., Maheen, R., & Shair, F. (2021). Trilemma association of energy consumption, carbon emission, and economic growth of BRICS and OECD regions: quantile regression estimation. *Environmental Science and Pollution Research*, *28*(13), 16014–16028. https://doi.org/10.1007/s11356-020-11823-8

Nepal, R., Paija, N., Tyagi, B., & Harvie, C. (2021). Energy security, economic growth and environmental sustainability in India: Does FDI and trade openness play a role? *Journal of Environmental Management*, *281*, 1–12. https://doi.org/https://doi.org/10.1016/j.jenvman.2020.111886

OECD. (2022). *OECD Indicators*. Oecd.Org. https://data.oecd.org/searchresults/?r=+f/type/indicators

Pata, U. K. (2021). Linking renewable energy, globalization, agriculture, CO2 emissions and ecological footprint in BRIC countries: A sustainability perspective. *Renewable Energy*, *173*, 197–208. https://doi.org/https://doi.org/10.1016/j.renene.2021.03.125

Ren, B., Li, H., Shi, J., Liu, Y., & Qi, Y. (2022). Identifying the key sectors and paths of the embodied energy in BRICS nations: A weighted multilayer network approach. *Energy*, *239*, 1–16. https://doi.org/10.1016/j.energy.2021.122091

Sharma, G. D., Tiwari, A. K., Erkut, B., & Mundi, H. S. (2021). Exploring the nexus between non-renewable and renewable energy consumptions and economic development: Evidence from panel estimations. *Renewable and Sustainable Energy Reviews*, *146*(April), 1–17. https://doi.org/10.1016/j.rser.2021.111152

Sinha, A., Gupta, M., Shahbaz, M., & Sengupta, T. (2019). Impact of corruption in public sector on environmental quality: Implications for sustainability in BRICS and next 11 countries. *Journal of Cleaner Production*, *232*, 1379–1393. https://doi.org/10.1016/j.jclepro.2019.06.066

Sohag, K., Taşkın, F. D., & Malik, M. N. (2019). Green economic growth, cleaner energy and militarization: Evidence from Turkey. *Resources Policy*, *63*, 1–9. https://doi.org/https://doi.org/10.1016/j.resourpol.2019.101407

Sterpu, M., Soava, G., & Mehedintu, A. (2018). Impact of Economic Growth and Energy Consumption on Greenhouse Gas Emissions: Testing Environmental Curves Hypotheses on EU Countries. In *Sustainability* (Vol. 10, Issue 9, pp. 1–14). https://doi.org/10.3390/su10093327

Topcu, E., Altinoz, B., & Aslan, A. (2020). Global evidence from the link between economic growth, natural resources, energy consumption, and gross capital formation. *Resources Policy*, *66*, 1–10. https://doi.org/https://doi.org/10.1016/j.resourpol.2020.101622

Usman, M., & Makhdum, M. S. A. (2021). What abates ecological footprint in BRICS-T region? Exploring the influence of renewable energy, non-renewable energy, agriculture, forest area and financial development. *Renewable Energy*, *179*, 12–28. https://doi.org/10.1016/j.renene.2021.07.014

Wahab, S., Imran, M., Safi, A., Wahab, Z., & Kirikkaleli, D. (2022). Role of financial stability, technological innovation, and renewable energy in achieving sustainable development goals in BRICS countries. *Environmental Science and Pollution Research*, *29*(32), 48827–48838. https://doi.org/10.1007/s11356-022-18810-1

Wang, X., Wei, Y., & Shao, Q. (2020). Decomposing the decoupling of CO2 emissions and economic growth in China's iron and steel industry. *Resources, Conservation and Recycling*, *152*, 1–10. https://doi.org/https://doi.org/10.1016/j.resconrec.2019.104509

Zeng, Q., & Yue, X. (2022). Re-evaluating the asymmetric economic policy uncertainty, conventional energy, and renewable energy consumption nexus for BRICS. *Environmental Science and Pollution Research*, *29*(14), 20347–20356. https://doi.org/10.1007/s11356-021-17133-x

Zhang, J., Alharthi, M., Abbas, Q., Li, W., Mohsin, M., Jamal, K., & Taghizadeh-Hesary, F. (2020). Reassessing the Environmental Kuznets Curve in Relation to Energy Efficiency and Economic Growth. *Sustainability*, *12*(20). https://doi.org/10.3390/su12208346