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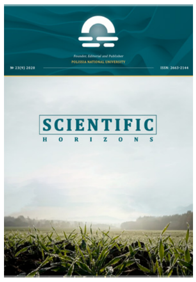

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Ecological and economic determinants of energy efficiency in European countries

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Abstract. Since economic development is often associated with an increase in greenhouse gas emissions, it is especially important to answer the question of whether it is possible to achieve sustainable economic development and improve energy efficiency at the same time, which implies a reduction in greenhouse gas emissions. The purpose of this study was to build models that can help find the environmental and economic determinants of energy efficiency in European countries. An ecological and economic determinants of energy efficiency indicators of 38 European countries were found based on panel regression models. The models were built based on statistical data characterizing the level of their economic development and consumption of diverse types of energy for 1995-2021. To obtain the necessary approximations of energy efficiency indicators, one of three types of models was used: the random effects method, the fixed effects method, or the pooled model. For this, appropriate statistical

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tests were used. As a result, it was found that the factors that have a statistically significant impact on the energy intensity of GDP in European countries include the intensity of carbon dioxide emissions, unemployment rate, primary energy consumption per capita, and gross electricity production per capita. The findings showed that determinants of primary energy consumption were domestic consumption of solid fossil fuels per capita, domestic natural gas consumption per capita, and primary energy consumption per capita. The study results generally confirm the modern-day thesis that economic development can be achieved while reducing greenhouse gas emissions. The monitoring of factors that have a statistically significant impact on the indicators under consideration can become an essential element of the modern energy efficiency management system of the national economies of European countries

Keywords: Energy intensity; economic growth; fossil fuel; primary energy consumption; GDP; electricity consumption; gas consumption; CO_2 emission

INTRODUCTION

The world is facing a growing risk of climate change caused by increased greenhouse gas emissions, which poses new challenges for governments of all countries. Economic development is usually associated with an increase in greenhouse gas emissions. Therefore, the question arises whether it is possible to achieve sustainable economic development and reduce greenhouse gas emissions at the same time. Besides, the EU's planned reduction of greenhouse gas emissions by at least 55% by 2030 will require significant additional investments, decarbonization of electricity generation, industry and transport, and energy efficiency in buildings. The identification of macroeconomic factors that significantly affect the energy efficiency of the European economies will allow national governments and regulators to develop effective mechanisms to achieve these goals.

Many scientific papers have covered this issue. Thus, Zioło *et al.* (2020) analysed the factors affecting the energy efficiency of the countries of the Organization for Economic Cooperation and Development (OECD). The results suggest a slight upward trend in the overall TFEE in OECD countries over the period under study, but developed OECD countries have higher levels than other OECD countries. Access to credit and the inflow of foreign direct investment that new energy-saving technologies bring can improve energy efficiency. The analysis showed that urbanization is not statistically significant for TFEE. Furthermore, the results show that increased energy efficiency leads to a reduction in carbon dioxide emissions.

The research of Klyvienė *et al.* (2020) is devoted to establishing the relationship between indicators that affect the green economic growth of the Eurozone countries, investigating the possible impact of environmental policy on macroeconomic variables such as GDP, investment, employment, and trade. Klyvienė *et al.* (2020) used the PVAR econometric model to estimate an influence of energy consumption, CO_2 emissions, and some another macroeconomic indicators on GDP growth in 19 Eurozone countries for 2000-2016. A short-term adverse impact of ecology-oriented economic policies on business activity was indicated. This is consistent with the traditional view that green economic policies can create added costs at all levels of the economic system. However, in the long term, the consequences of the implementation of environmental policy become positive.

Pimonenko *et al.* (2021) analysed 1,335 studies on economic stability and 1,811 studies on environmental protection. The results obtained showed a close correlation between the factors of energy efficiency and business efficiency, economic and macroeconomic stability. Considering this, the authors made a forecast for the development of energy efficiency. In this study, primary energy consumption was singled out as the basis for the energy efficiency forecast. The study used data from European countries (EU27) for 1991-2018.

Nobel Prize Winner S. Kuznets (1955) managed to prove the existence of a relationship between the level of human well-being and the state of the environment in the form of an inverse U-curve. The country's economic growth entails an increase in pollutant emissions, but after reaching a certain level of its development or the so-called extreme, the state of the environment gradually begins to improve. Such a dependence in the economic literature is called the ecological-economic Kuznets curve. Cherkashina (2020), using correlation-regression analysis, investigated the features of the ecological-economic Kuznets curve in the countries of the Visegrad group. The analysis showed that the ecological-economic Kuznets curve for the countries of the Visegrad group has the form of an N-shaped curve. This means that an increase in GDP per capita contributes to a decrease in CO_2 emissions, but not in the proportion in which people's well-being increases. The IMF, using statistics of 127 countries for two centuries, found evidence for an environmental-economic Kuznets curve, with an initial decline in energy demand due to low per capita income, followed by acceleration and then high-income saturation phases. It was confirmed that there is a downward trend in energy demand globally by about 1.2% per year, thus helping to stabilize energy demand in high-income countries.

Cibinskiene *et al.* (2020) and Laurens *et al.* (2017) investigated the issue of determining the key determinants of energy efficiency at different levels (not only the macro level). Zubeltzu-Jaka *et al.* (2018) and Pacheco *et al.* (2017) analysed the cause-and-effect relationships between indicators of economic development of countries and energy efficiency.

Thus, considering the above, the purpose of this study was to investigate the correlation between economic development and energy efficiency indicators in European countries based on the search for factors that significantly affect energy efficiency.

LITERATURE REVIEW

The correlation between energy efficiency and the level of economic development of the country is the subject of constant debate, and there is no consensus on this issue yet. Özcan & Özkan (2018) explored causal relationships between energy consumption, economic performance, and energy intensity in the G20 countries. The analysis suggested that these three variables tend to change in the same way in the long run. Furthermore, Granger causality tests show that there is a unidirectional causality that goes from energy intensity to economic performance, but not the other way around.

G. Bersalli *et al.* (2020) investigated the efficiency of the government policy in the field of renewable energy sources based on panel data from 20 Latin American and 30 European countries over 20 years. They confirm the effectiveness of such policies: the findings proved a positive and statistically significant impact on investment in renewable energy, being the main factors in all regions. It was also shown that tax incentives alone are insufficient to ensure the continued deployment of renewable energy technologies.

Kvach *et al.* (2021) pointed out the extremely high energy intensity of the Ukrainian economy and noted the need for "transformation of the electricity market by introducing market pricing principles that are uniform for all consumers of energy resources, energy efficient and energy-saving use and consumption of energy resources based on modern innovative technologies".

Segarra-Blasco & Jové-Llopis (2019) analysed the factors contributing to energy efficiency (EE) and the use of renewable energy (RE) sources by small and medium-sized enterprises in European countries. It was suggested that there is a corresponding complementarity between EE and RE practices and other methods of efficient use of resources. Furthermore, EE strategies mainly focus on cost savings and regulation, while RE strategies rely more on public support and environmental knowledge. Šumakaris *et al.* (2021) performed a systematic review of the literature devoted to the innovations in the identification of the efficiency determinants in the field of energy saving. According to the received data, the following determinants of energy-efficient innovations were identified at the micro level: cost savings; previous experience; technological capabilities; green tariffs; innovative opportunities; organizational innovations; financial resources; investments in tangible assets. Therewith, such determinants as the competitive environment, pressure from customers and suppliers, external cooperation in the field of knowledge, social pressure, and voluntary agreements are highlighted at the meso level. At the macro level, the determinants included state subsidies, current or future regulation. Ari *et al.* (2022), Sterlacchini (2020) and Costa-Campi *et al.* (2015) analysed the ways in which innovative technologies are introduced into the energy sector and their impact on energy efficiency factors.

MATERIALS AND METHODS

To find the ecological and economic determinants of energy efficiency in the article, the authors of this study used panel regression models, which were built using indicators of 38 European countries describing energy efficiency and macroeconomic indicators for 1995-2021. For this, statistical resources such as ESMS Indicator Profile (ESMS-IP), Enerdata (2022), World Bank, World Energy & Climate Statistics – Yearbook 2022 were used. To determine the level of energy efficiency of the national economies of European countries, authors used the values of primary energy intensity EI, carbon dioxide emission intensity CO_2_GDP, gross electricity production per capita EL_CAP, electricity available for final consumption per capita ELSUP_CAP, domestic consumption of natural gas, domestic consumption of solid fossil fuel (per capita) SOLID_CAP, primary energy consumption CON_ENER_EU, primary energy consumption per capita CON_ENER_EU_PC and gross available energy per capita CON_ENER_TOTAL_PC.

The level of development of the national economies of European countries was determined based on the following indicators: the ratio of exports of goods and services to GDP EXP_GDP, the unemployment rate UNEMP, GDP per capita GDPCAP, the ratio of direct foreign investments (net inflows) to GDP FDGDP, annual growth rates of GDP GDP_GROW, annual percentage growth rate of GDP per capita GDP_GROW_PC (Table 1).

Table 1. *Variables of the models*

EI	Energy intensity level of primary energy (MJ/$2017 PPP GDP)
CO2_GDP	Intensity of CO_2 emissions (kg per PPP $ of GDP)

Table 1, Continued

EXP_GDP	Exports of goods and services (% of GDP)
EL_CAP	Gross electricity production per capita (Thousand tonnes of oil equivalent)
UNEMP	Unemployment, total (% of total labour force) (modelled ILO estimate)
GDPCAP	GDP per capita (dollars USA)
CON_ENER_EU	Consumption of primary energy (Europe 2020-2030) (Million tonnes of oil equivalent)
CON_ENER_EU_PC	Consumption of primary energy (Europe 2020-2030) per capita (Million tonnes of oil equivalent)
CON_ENER_TOTAL_PC	Gross available energy per capita (kgoe)
ELSUP_CAP	Electricity, available for final consumption (Gigawatt-hour per capita)
FDGDP	Foreign direct investment, net inflows (% of GDP)
GASCAP	Inland consumption of gas – calculated (Terajoule per capita)
GDP_GROW	GDP growth (annual %)
GDP_GROW_PC	Annual percentage growth rate of GDP per capita based on constant local currency.
SOLID_CAP	Solid fossil fuels inland consumption (thousand tonnes per capita)

Source: *compiled by the authors of this study*

An identification of energy efficiency determinants in European countries will then be based on the one of three models: a pooled data model, a panel regression model with fixed or variable effects. A panel regression model that factors in the fixed effects method can be represented as follows:

$$Y_{it} = \alpha_i + \beta_k X_{k,it} + \varepsilon_{it}, \quad (1)$$

where i is the country, t is the time ($2000 \leqslant t \leqslant 2021$); α_i (i=1...38) is the unknown constant of the panel regression model; Y_{it} is the dependent variables; $X_{k,it}$ is the independent variables; β_k is the panel regression model parameters; ε_{it} is the error.

The model that factors in the random effects will look as follows:

$$Y_{it} = \alpha + \beta_k X_{k,it} + u_{it} + \varepsilon_{it}, \quad (2)$$

where α is the unknown constant of the panel regression model; u_{it} is the individual influence of the i^{th} country, which is called a random effect, similar to random errors, and is assumed to have a zero mean.

The pooled model of panel data or cross-sectional regression (pooled model) will look as follows:

$$Y = \alpha + \beta_k X_k + \varepsilon. \quad (3)$$

To create econometric models and conduct respective statistical tests, the authors of this study used the Eviews program. To select the variables of the regression model, authors used a stepwise regression method, in which factors are included in the model one by one until it becomes satisfactory. The order of inclusion of the factor was determined based on the correlation coefficient of the independent and dependent variables.

Having obtained the respective models with random effects, the Hausman test was implemented to determine the most appropriate method for constructing panel regression models – based on random effect (RE) or fixed effect (FE). To determine the priority between the panel model with fixed effects and the pool model with a common constant, the Wald test was used, which checks the non-zero regression coefficients.

RESULTS AND DISCUSSION

At the turn of the 20th century, the demand for energy increased sharply, caused by an increase in the rate of economic growth. From 1900 to 1950, with the spread of electric lighting and the development of all modes of transport, the demand for primary energy almost doubled. Economic growth also picked up sharply, prompting a shift from biomass to fossil fuels as the main source of primary energy. For example, in the United States, GDP per capita in 1950 was more than double what it was in 1900. The use of oil (in addition to coal) in the 20th century dramatically increased production and consumption. Fossil fuels lose from 40% to 70% of their energy when converted into electrical or mechanical energy, which is a lot, but not compared to almost complete losses when burning wood or other biomass. Although modern economies need increased energy resources, McKinsey & Company experts predict that the demand for primary energy by 2030 will slow down primarily due to the rapid spread of renewable energy sources (Fig. 1).

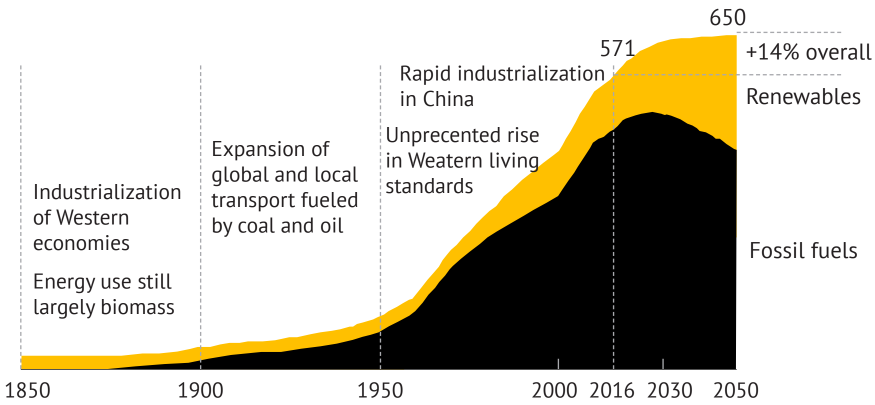

Figure 1. *Global primary energy demand, millions terajoules*

Source: *(Sharma et al., 2019)*

Increasing the level of energy efficiency is a necessary condition for the complete decarbonization of EU economy and achieving independence from Russian fossil fuels. The close relationship between macroeconomic stability and energy efficiency has been more clearly seen recently at the international level, especially after the beginning of Russia's full-scale aggression against Ukraine. Fossil fuel prices caused the biggest inflationary shock in Europe since Second World War, outpacing the oil crisis of the 1970s. In September 2022, the price of energy was 40.8% higher than a year earlier (Fig. 2).

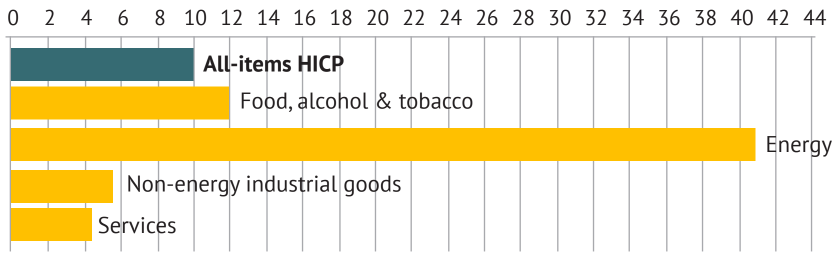

Figure 2. *Euro area annual inflation, September 2022, %*

Source: *(Eurostat, 2022)*

Authors first estimate the level of primary energy intensity, which is the ratio between primary energy input and gross domestic product measured at purchasing power parity. Overall, total energy consumption per unit of GDP in the world declined much less in 2021 than in the previous few years (averaging -1.5% per year from 2000 to 2020). All this significantly complicates the task of increasing the average temperature by no more than 2°C. To achieve these indicators, a reduction of 3.5% per year should be observed. Experts note that such a slowdown is mainly due to an increase in energy consumption in 2021 (Enerdata, 2022).

As a result, a panel regression model was obtained to assess the energy intensity of EI (see Table 3). It is based on the random effect, since the results of the Houseman test showed that there is no reason to reject the hypothesis about the advisability of using a random effect (Table 2).

Table 2. *Results of the Hausman test for the EI model*

Test Summary	Chi-Sq. statistic	Prob.
Cross-section random	9.356953	0.0528

Source: *compiled by the authors of this study using Eviews based on data form ESMS Indicator Profile (ESMS-IP), Enerdata (2022), World Bank, World Energy & Climate Statistics – Yearbook (2022)*

Table 3. *Model for estimating of the energy intensity EI*

Dependent Variable: EI				
Sample: 1995-2021		Periods included: 27		
Cross-sections included: 38		Total panel (unbalanced) observations: 1026		
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
C	0.670808	0.175068	3.831692	0.0001

Table 3, Continued

Dependent Variable: EI				
Sample: 1995-2021		Periods included: 27		
Cross-sections included: 38		Total panel (unbalanced) observations: 1026		
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
CO2_GDP	5.128102	0.114631	44.73559	0.0000
UNEMP	0.044043	0.003949	11.15197	0.0000
CON_ENER_TOTAL_PC	0.000410	4.12E-05	9.949097	0.0000
EL_CAP	584.2782	133.0672	4.390851	0.0000
R-squared	0.840511	F-statistic		998.6714
Adjusted R-squared	0.839670	Prob(F-statistic)		0.000000

Source: *compiled by the authors of this study using Eviews based on data form ESMS Indicator Profile (ESMS-IP), Enerdata (2022), World Bank, World Energy & Climate Statistics – Yearbook (2022)*

Of all macroeconomic indicators, only the unemployment rate has a statistically significant impact on the energy intensity of GDP, and its growth entails an increase in energy intensity. This can be explained by the fact that more developed economies naturally have lower unemployment rates and higher levels of energy efficiency. Carbon dioxide emissions CO2_GDP, gross available energy per capita CON_ENER_TOTAL_PC and gross electricity production per capita EL_CAP have a positive effect on the energy intensity of GDP in European countries.

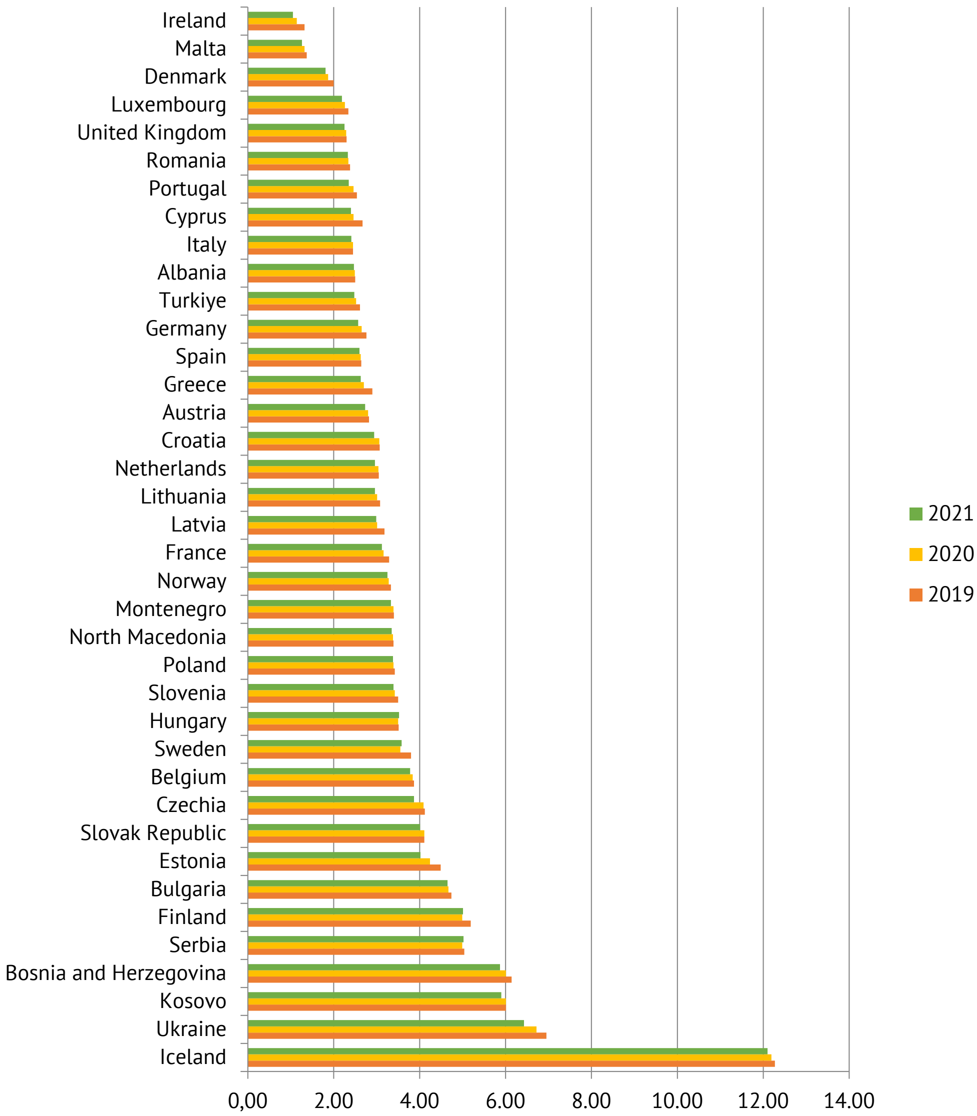

Figure 3. *Energy intensity of the GDP of European countries (MJ/$2017 PPP GDP)*
Source*: compiled by the authors of this study based on World Bank statistics (n.d.)*

According to the results of the Hausman test (Table 4), the use of panel regression with fixed effects is better for estimating carbon dioxide emissions CO2_GDP. Carbon dioxide emissions CO2_GDP are associated with the combustion of fossil fuels and the production of cement. These include carbon dioxide generated during the consumption of solid, liquid, and gaseous fuels and the combustion of associated gas.

Table 4. *Results of the Hausman test for the CO2_GDP model*

Test Summary	Chi-Sq. Statistic	Prob.
Cross-section random	95.595207	0.0000

Source: *compiled by the authors of this study using Eviews based on data form ESMS Indicator Profile (ESMS-IP), Enerdata (2022), World Bank, World Energy & Climate Statistics – Yearbook (2022)*

As a result, model was obtained with EI, GDPCAP, ELSUP_CAP and EXP_GDP as explanatory variables (Table 5). Interestingly, as the share of electricity available for final consumption per capita increases, carbon dioxide emissions per capita will decrease. Considering the current trends in electricity generation in Western Europe, which consist in the almost complete abandonment of the use of coal in the energy sector, primarily for environmental reasons, such a correlation between carbon dioxide emissions and electricity supply is expected.

Table 5. *Model for estimating of CO2_GDP*

Dependent Variable: CO2_GDP				
Sample: 1995-2021			Periods included: 27	
Cross-sections included: 38			Total panel (unbalanced) observations: 1026	
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
C	-0.445314	0.027107	-16.42829	0.0000
EI	0.106754	0.003222	33.12883	0.0000
GDPCAP	-1.31E-06	2.53E-07	-5.178391	0.0000
ELSUP_CAP	-17.47378	1.055253	-16.55886	0.0000
EXP_GDP	-0.001883	0.000258	-7.308944	0.0000
Dummy variables				
Belgium	0.540954		Austria	0.584837
Bulgaria	0.397835		Poland	0.530677
Czech Republic	0.523956		Portugal	0.499157
Denmark	0.641431		Romania	0.470945
Germany	0.563469		Slovenia	0.507424
Estonia	0.634958		Slovak Republic	0.387735
Ireland	0.778473		Finland	0.483719
Greece	0.557533		Sweden	0.459980
Spain	0.500420		Iceland	0.163991
France	0.403355		Norway	0.750855
Croatia	0.445059		Great Britain	0.520356
Italy	0.528905		Montenegro	0.434695
Cyprus	0.619616		North Macedonia	0.535257
Latvia	0.396583		Albania	0.379178
Lithuania	0.357618		Serbia	0.463215
Luxembourg	1.029918		Turkey	0.479732
Hungary	0.455413		Bosnia and Herzegovina	0.369065
Malta	0.764837		Kosovo	0.473817
Netherlands	0.582753		Ukraine	base
R-squared	0.902638		Prob(F-statistic)	0.000000
Adj. R-squared	0.897403			

Source: *compiled by the authors of this study using Eviews based on data form ESMS Indicator Profile (ESMS-IP), Enerdata (2022), World Bank, World Energy & Climate Statistics – Yearbook (2022)*

Renewable energy technologies for electricity generation are the main tool for the decarbonization of the energy sector around the world. Government policies to promote their spread have been carried out in developed countries since 1980, and since the 2000s, increasingly more developing countries have begun to implement an analogous strategy in the energy sector. European countries are building their energy policies to completely phase out coal in electricity generation within this decade. Furthermore, as Figures 4 and 5 suggest, there is a clear upward trend in the share of electricity in total final energy consumption in Europe and in the world as a whole, and an increase in the share of wind and solar power plants in electricity generation. Because of this, an increase in the share of electricity available for final consumption naturally leads to a decrease in carbon dioxide emissions, which is consistent with the resulting model.

By 2030, the European Parliament has planned to increase the use of renewable energy sources and dramatically reduce energy consumption. By 2030, the Renewable Energy Directive (RED) aims to increase the share of renewable energy sources in total energy consumption in the EU to 45%. An analogous goal is also planned by the European Commission in a special RepowerEU package. The Fit for 55 package also includes a revision of the Energy Efficiency Directive (EED) to achieve a 55% greenhouse gas emission target. Today, the EED directive sets the level of EU energy saving that the EU must achieve by 2030 to reach the goal of 32.5% energy efficiency improvement (Parliament backs boost..., 2022).

The results of the Wald test for zero coefficients of dummy variables for the resulting model showed the feasibility of using a fixed effects model as opposed to a model based on a pool of data (Fig. 4, 5).

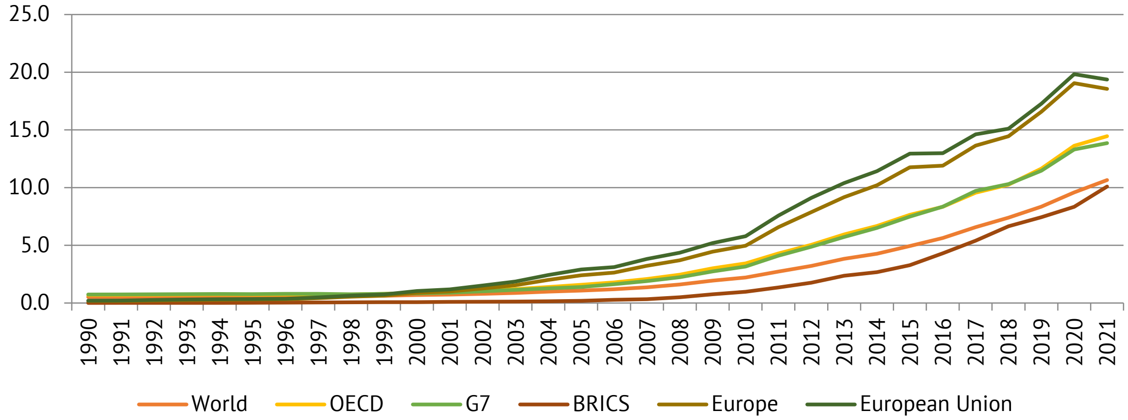

Figure 4. *Share of wind and solar power plants in electricity generation (%)*
Source*: compiled by the authors of this study based on World Energy & Climate Statistics – Yearbook (2022)*

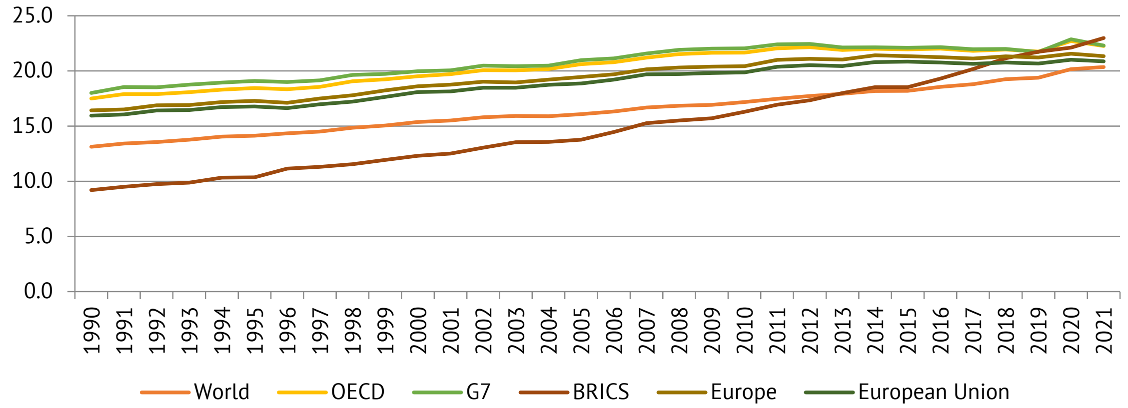

Figure 5. *The share of electricity in the total final energy consumption (%)*
Source*: compiled by the authors of this study based on World Energy & Climate Statistics – Yearbook (2022)*

Thus, according to the constructed panel regression model, the macroeconomic determinants of the carbon dioxide emissions intensity are GDP per capita and the share of exports in GDP. The greater the value of both these factors, the higher the level of economic development of the country, and, consequently, the higher energy efficiency, which is a characteristic feature of the modern eco-oriented economy of European countries. This is consistent with the fact that GDP per capita and the share of exports in GDP negatively affect the intensity of carbon dioxide emissions. Figures 6, 7 show the evolution of these indicators in the EU in 2021. Of the 38 European countries analysed in this study, Luxembourg had the highest level of GDP per capita in 2021 – $133,590.16, while Ukraine had the lowest value – $4,568.91.

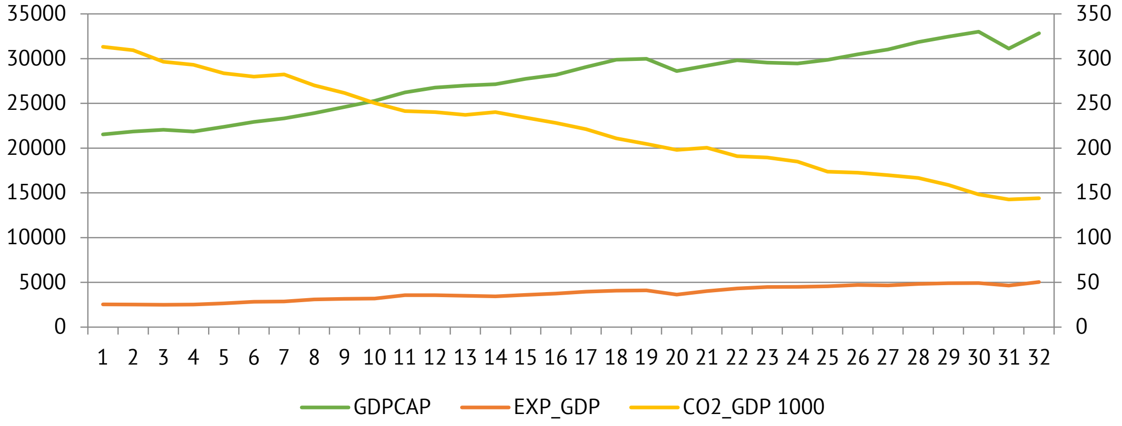

Figure 6. *Dynamics of changes in GDP per capita, the share of exports in GDP and an intensity of carbon dioxide emissions in the EU in 2021*

Source*: compiled by the authors of this study based on World Energy & Climate Statistics – Yearbook (2022)*

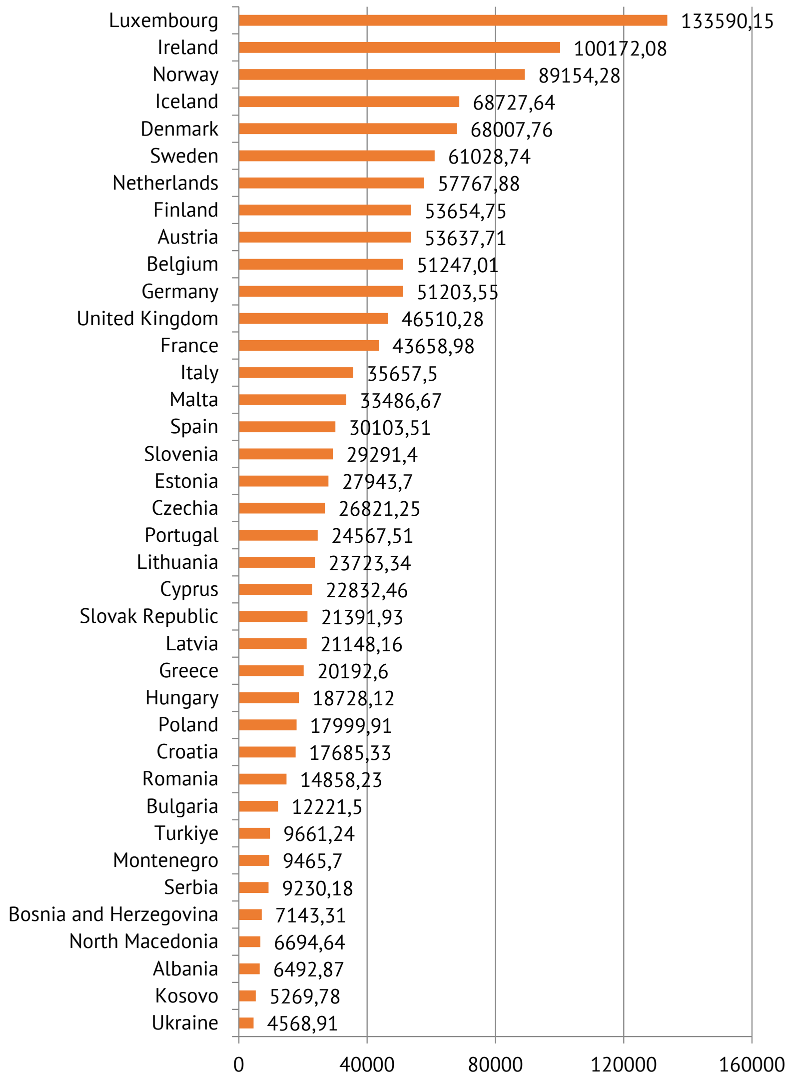

Figure 7. *GDP per capita in 2021 (USD)*

Source*: compiled by the authors of this study*

As is known, the European Union has pledged to reduce energy consumption by 20% by 2020 compared to the baseline forecasts. In other words, the EU plans to consume just over 1,483 million tonnes of oil equivalent in primary energy and just over 1,086 million tonnes in final energy in 2020. By 2030, a reduction of at least 32.5% is planned (Saheb *et al.*, 2018).

The maximum consumption of primary energy in the EU occurred in 2006. In 2021, consumption was 18.1% below the peak value. The distance from the actual level of primary energy consumption and the target level for 2030 was 34% in 2006. In 2020, the distance decreased to 9.5% and increased to 16.0% in 2021 (Fig. 8).

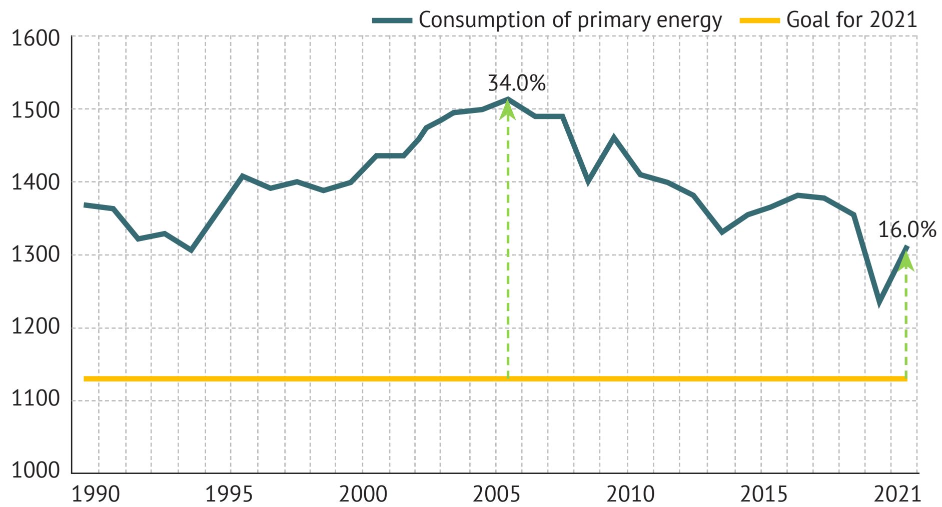

Figure 8. *Primary energy consumption in the EU (distance to 2030), million toe*
Source*: compiled by the authors of this study based on ESMS Indicator Profile*

The CON_ENER_EU primary energy consumption estimation model was obtained using the fixed effects method, since the results of the Hausman and Wald tests showed the advantage of FEM models over random effects and data pool models (Table 6). Domestic consumption of solid fossil fuels per capita, domestic consumption of natural gas per capita and available gross energy per capita were statistically significant (Table 7). Moreover, all variables have a positive effect on the resulting indicator. Macroeconomic characteristics were not statistically significant when assessing CON_ENER_EU.

Table 6. *Results of the Hausman test for CON_ENER_EU model*

Test Summary	Chi-Sq. Statistic	Prob.
Cross-section random	98.785112	0.0000

Source: *compiled by the authors of this study using Eviews based on data form ESMS Indicator Profile (ESMS-IP), Enerdata (2022), World Bank, World Energy & Climate Statistics – Yearbook (2022)*

Table 7. *Model for estimating of CON_ENER_EU*

Dependent Variable: CON_ENER_EU				
Sample: 1995-2021		Periods included: 27		
Cross-sections included: 38		Total panel (unbalanced) observations: 1026		
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
C	31.00476	1.738194	17.83734	0.0000
SOLID_CAP	3611.730	612.7344	5.894446	0.0000
GASCAP	217.7291	40.91441	5.321575	0.0000
CON_ENER_EU_PC	0.001715	0.000454	3.779405	0.0002
Dummy variables				
Belgium	38.45966		Austria	28.35773
Bulgaria	9.371768		Poland	86.95388
Czech Republic	23.31707		Portugal	28.49187

Table 7, Continued

Dependent Variable: CON_ENER_EU				
Sample: 1995-2021		**Periods included: 27**		
Cross-sections included: 38		**Total panel (unbalanced) observations: 1026**		
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
Denmark	17.64596	Romania		35.06615
Germany	293.8608	Slovenia		4.204755
Estonia	9.026506	Slovak Republic		11.11043
Ireland	13.19174	Finland		27.23074
Greece	16.26054	Sweden		50.23856
Spain	124.7226	Iceland		-8.230735
France	246.4671	Norway		20.34210
Croatia	13.68862	Great Britain		196.7502
Italy	158.7604	Montenegro		4.597591
Cyprus	11.97060	North Macedonia		3.120500
Latvia	9.924953	Albania		16.02440
Lithuania	10.10217	Serbia		4.436275
Luxembourg	-13.74459	Turkey		108.3585
Hungary	21.20021	Bosnia and Herzegovina		1.913920
Malta	6.526938	Kosovo		2.547697
Netherlands	48.95593	Ukraine		base
R-squared	0.991918	Prob (F-statistic)		0.000000
Adjusted R-squared	0.991491			

Source: *compiled by the authors of this study using Eviews based on data form ESMS Indicator Profile (ESMS-IP), Enerdata (2022), World Bank, World Energy & Climate Statistics – Yearbook (2022)*

The analysis showed that the primary energy consumption per capita CON_ENER_EU_PC is better approximated by FEM models, since the results of the Hausman test indicated that the probability of accepting the null hypothesis about the appropriateness of using REM models is close to zero (Table 8). Furthermore, the Wald test for zero coefficients for dummy variables confirmed the feasibility of using the FEM model as opposed to the data pool model.

The macroeconomic determinants of primary energy consumption per capita in European countries were the unemployment rate and the share of exports in GDP. An increase in both these indicators will reduce primary energy consumption per capita in European countries, while an increase in domestic consumption of natural gas per capita and available electricity for final consumption per capita will lead to an increase in primary energy consumption per capita (Table 9).

Table 8. *Results of the Hausman test for CON_ENER_EU_PC model*

Test Summary	Chi-Sq. Statistic	Prob.
Cross-section random	77.65911	0.0000

Source: *compiled by the authors of this study using Eviews based on the base of data form ESMS Indicator Profile (ESMS-IP), Enerdata (2022), World Bank, World Energy & Climate Statistics – Yearbook (2022)*

Table 9. *Model for estimating of CON_ENER_EU_PC*

DependentVariable: CON_ENER_EU_PC				
Sample: 1995-2021			**Periods included: 27**	
Cross-sections included: 38			**Total panel (unbalanced) observations: 1026**	
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
C	1363.705	107.3005	12.70921	0.0000
CON_ENER_EU	8.900696	1.363705	6.526851	0.0000
GASCAP	23965.38	1587.116	15.09995	0.0000

Table 9, Continued

DependentVariable: CON_ENER_EU_PC				
Sample: 1995-2021			Periods included: 27	
Cross-sections included: 38			Total panel (unbalanced) observations: 1026	
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
UNEMP	-14.49307	2.943106	-4.924412	0.0000
EXP_GDP	-4.070700	1.033568	-3.938492	0.0001
ELSUP_CAP	240955.6	4789.824	50.30572	0.0000
Dummy variables				
Belgium	1146.091		Austria	-187.1280
Bulgaria	42.51561		Poland	-554.2341
Czech Republic	641.3436		Portugal	-431.5182
Denmark	90.66606		Romania	-894.3206
Germany	-2380.800		Slovenia	439.5151
Estonia	1370.362		Slovak Republic	63.79852
Ireland	-54.64530		Finland	806.4769
Greece	-68.66128		Sweden	417.6613
Spain	-1043.346		Iceland	4265.916
France	-1586.065		Norway	-2200.965
Croatia	-482.1874		Great Britain	-2251.594
Italy	-2085.157		Montenegro	-485.0338
Cyprus	1453.453		North Macedonia	-280.4422
Latvia	-154.0050		Albania	-803.9735
Lithuania	80.01286		Serbia	-224.3687
Luxembourg	2653.527		Turkey	-1631.744
Hungary	-536.5389		Bosnia and Herzegovina	82.32486
Malta	2903.606		Kosovo	-485.0338
Netherlands	109.2699		Ukraine	base
R-squared	0.991091		Prob(F-statistic)	0.000000
Adjusted R-squared	0.990596			

Source: *compiled by the authors of this study using Eviews based on data form ESMS Indicator Profile (ESMS-IP), Enerdata (2022), World Bank, World Energy & Climate Statistics – Yearbook (2022)*

The parameters of the model for estimating gross available energy per capita CON_ENER_TOTAL_PC are presented in Table 11. In this case, the Hausman test (Table 10) confirmed the absence of grounds for rejecting the null hypothesis, and therefore, the REM panel regression model was chosen. The unemployment rate has a negative impact on this indicator, as in the previous model. This can be substantiated by the fact that an increase in the unemployment rate, which also signals a decrease in the level of economic development of the country, will lead to a potential decrease in the total energy consumption per capita in the country. This relationship between the UNEMP unemployment rate and total energy consumption per capita can be clearly observed in Figure 9. Consumption of gas (Fig. 9) and electricity available for final consumption per capita in highly developed countries is generally somewhat higher compared to other European countries, which is also reflected in the model.

Table 10. *Results of the Hausman test for CON_ENER_TOTAL_PC model*

Test Summary	Chi-Sq. Statistic	Prob.
Cross-section random	6.337851	0.1753

Source: *compiled by the authors of this study using Eviews based on data form ESMS Indicator Profile (ESMS-IP), Enerdata (2022), World Bank, World Energy & Climate Statistics – Yearbook (2022)*

Table 11. *Model for estimating of CON_ENER_TOTAL_PC*

Dependent Variable: CON_ENER_TOTAL_PC				
Sample: 1995–2021			**Periods included: 27**	
Cross-sections included: 38			**Total panel (unbalanced) observations: 1026**	
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
C	944.2367	184.1448	5.127685	0.0000
UNEMP	-14.89694	3.103852	-4.799500	0.0000
EL_CAP	2705063	54424.80	49.70276	0.0000
GASCAP	18020.21	1556.506	11.57735	0.0000
R-squared	0.838757		F-statistic	985.7421
Adjusted R-squared	0.837906		Prob(F-statistic)	0.000000

Source: *compiled by the authors of this study using Eviews based on data form ESMS Indicator Profile (ESMS-IP), Enerdata (2022), World Bank, World Energy & Climate Statistics – Yearbook (2022)*

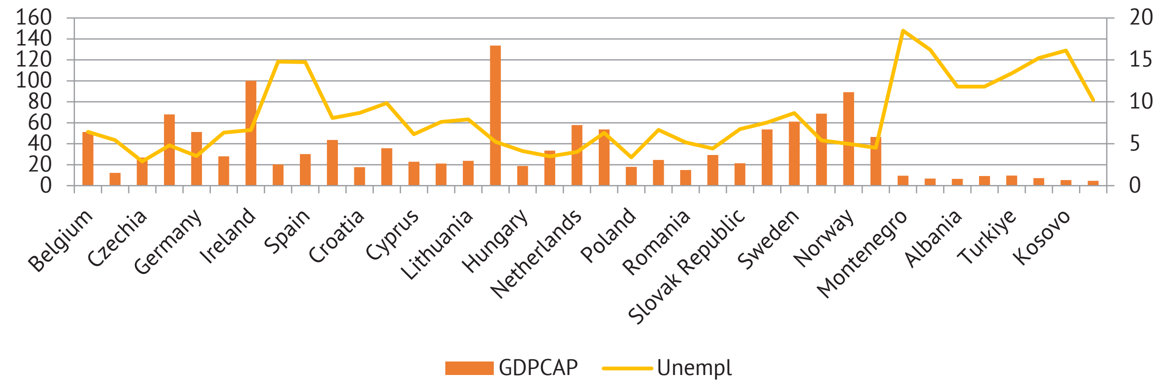

Figure 9. *GDP per capita (thousand USD) and unemployment rate in European countries in 2021*
Source*: compiled by the authors of this study based the base of World Bank statistics (n.d.)*

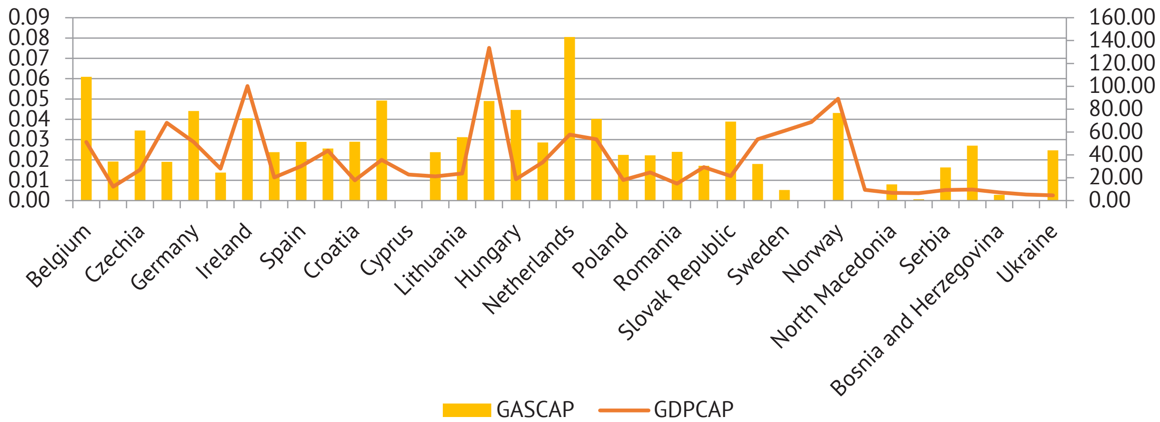

Figure 10. *GDP per capita (thousand USD) and inland consumption of gas GASCAP (Terajoule per capita) in European countries in 2021*
Source*: compiled by the authors of this study based on World Bank statistics (n.d.)*

In 2023, an agreement was signed between the European Parliament and the Council to strengthen the EU Energy Efficiency Directive, highlighting the EU's intention to become climate neutral by 2050. This agreement is the next step towards the implementation of the "Ready for 55 years" package for the performing of the European Green Deal and the REPowerEU plan. Now the EU countries are obliged to consider energy efficiency indicators in domestic and foreign policy, planning and making important investment decisions in the energy and other sectors. (European Green Deal, 2023).

The first principle of energy efficiency means the maximum use of economic measures to improve energy efficiency in the formation of energy policy and making appropriate investment decisions. The agreement sets an EU energy efficiency target of 11.7% by 2030, which exceeds the original proposal by the European Commission and requires Member States collectively to provide further reductions in final and primary energy consumption compared to energy consumption projections made in 2020.

The most explanatory variables appeared in the model of primary energy consumption per capita, namely, primary energy consumption, domestic natural gas consumption per capita, unemployment rate, the ratio of exports of goods and services to GDP and electricity available for final consumption per capita. Gross available energy per capita depends on the unemployment rate, gross electricity production per capita, domestic consumption of natural gas per capita.

The models constructed in this study strongly suggest the dependence of economic growth and energy efficiency of European countries. Since the variables GDPCAP and EXP_GDP, which determine the level of economic growth in the country, are explanatory variables in the CO2_GDP estimation model and their growth negatively affects the intensity of CO2 emissions, it can be argued that the possibility of simultaneously achieving sustainable economic development and reducing the intensity of carbon dioxide emissions. The positive dependence of the energy intensity of EI on the level of unemployment also serves as confirmation that economic growth in European countries is accompanied by an improvement in the level of energy efficiency. It is possible to achieve sustainable economic development while simultaneously reducing greenhouse gas emissions. The existence of such dependence, which is inherent in developed economies, is also evidenced by other studies (e.g., Cherkashina (2020), Klyvienė & Kėdaitienė (2020)). This is also consistent with the ecological-economic Kuznets curve, according to which the country's economic growth causes the growth of pollutant emissions, but after reaching a certain level of its economic development, the country's ecology gradually begins to improve.

CONCLUSIONS

The models obtained in this study help identify the ecological and economic determinants of primary energy intensity, carbon dioxide emission intensity, primary energy consumption and gross available energy per capita in 38 European countries. Thus, according to the models obtained, the factors on which the value of the energy intensity of the GDP for European countries significantly depends include the intensity of carbon dioxide emissions, the unemployment rate, primary energy consumption per capita, and gross electricity production per capita. The determinants of primary energy consumption were domestic consumption of solid fossil fuels per capita, domestic consumption of natural gas per capita and primary energy per capita. As a result, the existence of a positive relationship between energy efficiency and economic growth in European countries was generally confirmed as well as the possibility of simultaneously achieving sustainable economic development and reducing the intensity of carbon dioxide emissions. Monitoring of macroeconomic and other factors that have a statistically significant impact on energy efficiency will make it possible to form a flexible system for managing the energy efficiency of the national economies in European countries.

Therefore, the development of such monitoring systems at the macro level, first of all, can be the subject of subsequent scientific research devoted to the analysis of the relationship between energy efficiency and economic growth.

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CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

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Екологічні та економічні детермінанти енергоефективності в європейських країнах

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Анотація. Оскільки економічний розвиток часто пов'язаний зі збільшенням викидів парникових газів, особливо важливо відповісти на питання, чи можливо досягти сталого економічного розвитку і одночасно підвищити енергоефективність, що передбачає скорочення викидів парникових газів. Метою цього дослідження була побудова моделей, які можуть допомогти знайти еколого-економічні детермінанти енергоефективності в європейських країнах. Екологічні та економічні детермінанти показників енергоефективності 38 європейських країн були знайдені на основі панельних регресійних моделей. Моделі побудовані на основі статистичних даних, що характеризують рівень їх економічного розвитку та споживання різних видів енергії за 1995-2021 роки. Для отримання необхідних апроксимацій показників енергоефективності використовувався один з трьох типів моделей: метод випадкових ефектів, метод фіксованих ефектів або об'єднана модель. Для цього використовувалися відповідні статистичні тести. В результаті було виявлено, що до факторів, які мають статистично значущий вплив на енергоємність ВВП в європейських країнах, належать інтенсивність викидів вуглекислого газу, рівень безробіття, споживання первинної енергії на душу населення та валове виробництво електроенергії на душу населення. Результати дослідження показали, що визначальними факторами споживання первинної енергії є внутрішнє споживання твердого викопного палива на душу населення, внутрішнє споживання природного газу на душу населення та споживання первинної енергії на душу населення. Результати дослідження в цілому підтверджують сучасну тезу про те, що економічний розвиток може бути досягнутий при одночасному скороченні викидів парникових газів. Моніторинг факторів, які мають статистично значущий вплив на досліджувані показники, може стати важливим елементом сучасної системи управління енергоефективністю національних економік європейських країн

Ключові слова: енергоємність; економічне зростання; викопне паливо; споживання первинної енергії; ВВП; споживання електроенергії; споживання газу; викиди CO_2