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SELECTED DETERMINANTS OF THE DEVELOPMENT OF RENEWABLE ENERGY SOURCES IN THE MEMBER STATES OF THE EUROPEAN UNION

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ABSTRACT: The objective of this study is to explore the relationship between selected indicators of SDG7, supplemented by the variables of GDP and carbon dioxide emission contract prices, and the consumption of energy from renewable sources in the European Union. The research problem of the study is whether it is possible to explain the consumption of energy from renewable sources in the European Union from 2010 to 2020 within the group of selected indicators for SDG 7 supplemented by GDP variable and variable CO_2 emission futures contracts. Based on conducted econometric research, it was proved that there was a certain interdependence and causality of selected factors on the development of renewable energy sources, which varied depending on the EU Member State. By making a critical evaluation of the obtained models, it was found that only in 10 cases (countries) can they be considered correct.

KEYWORDS: renewable energy consumption model, causality analysis, RES in the European Union

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Introduction

Nowadays, there is a growing emphasis by the European Union member states on the use of renewable energy sources, which had its beginning in the 1990s (Molo, 2016). In 1997, the 'White Paper for a Community Strategy and Action Plan' was presented. Energy for the future: Renewable sources of Energy laid the foundation for the European Union's energy policy in the area of renewable energy sources (European Commission, 1997). The document proposes a target of doubling the share of renewable energy in gross energy consumption in the European Union from 6% to 12% by 2010 (Scarlat et al., 2015). In 2009, the Renewable Energy Directive (Directive, 2009) indicated that by 2020, 20% of total energy consumption in the European Union must mandatorily come from renewable sources (Directive, 2009). In 2018, The European Union adopted a revised Renewable Energy Directive (Directive, 2018). It set a new target that at least 32% of the final energy consumed in the European Union should come from renewable sources by 2030. In 2022, the European Union's high climate ambitions were reflected in the European Parliament's vote in favour of increasing the share of RES in global energy consumption to 45%. The final decision, however, requires a negotiated agreement with the member countries (European Commission, 2022). In 2020, the share of RES in the EU countries' energy consumption varied widely, with the EU-27 average at 22%. The leader of the list is Sweden, which met about 60% of its energy needs from renewable sources (Eurostat, 2022) (Figure 1). The varying performance in the area of RES consumption in total energy consumption may be due to a number of reasons, such as, for example, the attitude of countries towards the development of a 'green economy', which can be reflected in the reduction of negative climate and environmental changes, as well as stimulate economic growth (Chlebisz et al., 2021).

Ensuring affordable access to sources of stable, sustainable and modern energy for all is also the focus of the seventh Sustainable Development Goal (Tomala et al., 2021), which was proposed in the Agenda 2030 document by the United Nations in 2015. It singles out the main tasks for achieving this goal by 2030, which include ensuring universal access to affordable, reliable and modern energy services, significantly increasing the share of renewable sources in the global energy mix, and doubling the rate of global energy efficiency (United Nations, 2015). The European Union is implementing the Agenda 2030, and the projects it is implementing correspond to the UN guidelines. Within the EU, a number of indicators have also been adopted to monitor progress towards the Sustainable Development Goals (Pleśniarska, 2019), including in the area of clean and accessible energy.

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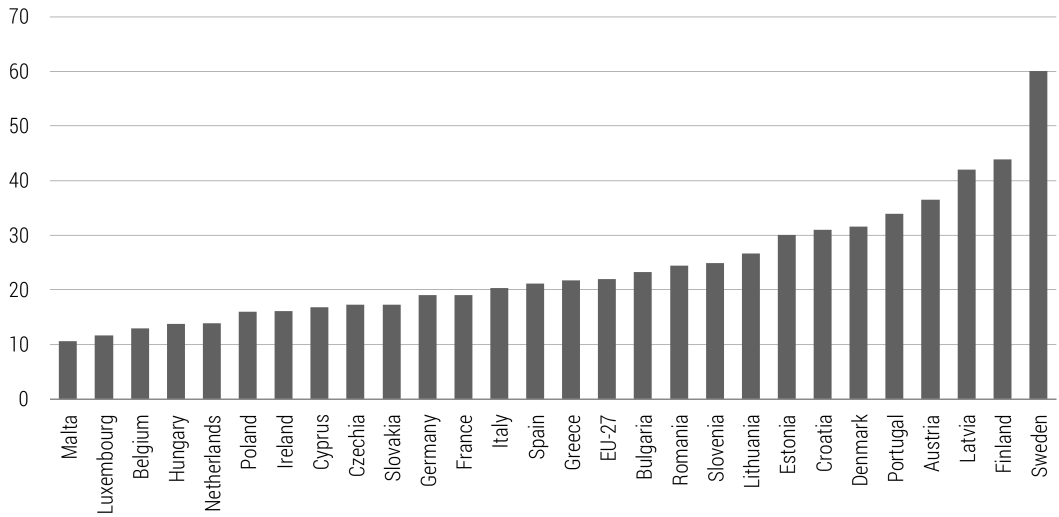

Figure 1. Share of renewables in gross final energy consumption in the European Union countries in 2020 [%]

Source: Eurostat (2022).

Selected determinants of renewable energy development have been identified. However, to the best of our knowledge, there is a lack of studies that focus on selecting variables for the model primarily based on the selected indicators of the 7th Sustainable Development Goal (SDG7) related to clean and accessible energy. The research problem of the study is whether it is possible to explain the consumption of energy from renewable sources in the European Union within the group of selected indicators for SDG 7 supplemented by GDP variable and variable CO_2 emission futures contracts. By identifying this research gap, the objective of this study is to analyse and understand the connections that can explain the development of renewable energy sources in EU countries. The existing research findings on the impact of selected determinants on the consumption of energy from renewable sources indicate the need for further research to advance the field. In our study, we identify specific determinants of renewable energy consumption in each member country based on a pre-determined selection of variables for new time frames. Empirical research is based on multiple regression analysis, and Eurostat data for the EU member states from 2010 to 2020.

The contribution of this study to the literature on the subject arises from the following facts. Firstly, the level of dependence (or lack thereof) between selected explanatory variables (gross domestic product, energy efficiency, final energy consumption in households, primary energy consumption, and futures contracts on CO_2 emissions) and the explained variable of renewable energy consumption in European Union member states has been identified, indicating diverse and ambiguous results. Secondly, the research broadens the existing knowledge in the area of the significance of selected determinants of renewable energy consumption.

The development of renewable energy sources is determined by a number of factors, the occurrence of which can determine the shift away from conventional energy sources and towards a low-carbon economy. For example, economic growth determines an increase in energy demand, including clean energy from RES (Saad & Taleb, 2017; Uçan et al., 2014). On the other hand, Cador and Padovano (2016) points out that increased economic activity entails higher energy demand, which leads to more energy being generated by conventional energy sources, which are more flexible in relation to RES due to the ease of importing or storing them. However, the increase in energy demand is reflected in increased investment in RES, which makes the long-term impact of increased income on RES consumption growth significant and positive. Economic growth that supports the transition to a low-carbon economy requires increased energy efficiency, understood as producing the same level of output with less energy (Özcan & Özkan, 2018). Reducing the energy intensity of the economy is a priority and key element of energy policy, as it measurably supports the achievement of its other goals (Firlej, 2012). This leads to the conclusion that policies aimed at increasing energy efficiency promote investment in RES and increased consumption of clean energy. Economies based on renewable energy sources are characterised by high energy efficiency, which is one of the factors of their international competitiveness. The need to meet competition and maintain or increase competitiveness requires further actions to increase energy efficiency. Examples of such actions can include investments in increasingly efficient, economically profitable, and advanced technologies of renewable energy sources while simultaneously reducing the consumption of conventional energy. A stimulant for investment in clean energy technologies can also be the carbon emission allowances that the EU grants to member states and the energy-intensive businesses operating within them. There is a close relationship between the EU's set carbon emissions limit and the limited supply of allowances, which gives a boost to RES development. The impact of futures contract prices on renewable energy consumption can be considered in two ways. Firstly, if these prices are at a high level, it constitute a destructive factor for the finances of companies whose activities contribute to environmental pollution. The need to spend significant amounts on carbon dioxide emission fees may encourage the search for alternative solutions. In such a situation, investments in renewable energy sources seem to be a pragmatic solution that will help reduce or avoid fees for harmful emissions, but will

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also be reflected in other aspects, such as shaping a positive image of a socially responsible enterprise.

As a result of the increase in investment outlays on clean energy technologies, the consumption of renewable energy increases, which has a positive effect on reducing environmental pollution. For example, the research by Bekun (2021) proved the positive impact of the consumption of energy from renewable sources on the reduction of carbon dioxide emissions.

An overview of the literature

A literature search reveals a plethora of studies on attempts to construct explanatory models of renewable energy consumption in the European Union. These models are diverse due to many aspects, which include the number and type of exogenous variables, the econometric methods used and the period of study. The results obtained in these studies are diverse and sometimes mutually exclusive. This prompts further research aimed at searching for the most optimal model of RES consumption in total energy consumption.

Table 1. The previous studies explain renewable energy consumption in the European Union

Author	Publication year	Study period	Variables under study
Marques et al.	2010	1990-2006	CO_2 emissions, energy dependency, income.
Marinaș et al.	2018	1990-2014	Economic growth
Papież et al.	2018	1995-2014	Energy security, environmental well-being, economics, politics.
Akadiri et al.	2019	2007-2017	GDP per capita
Anton and Afloarei Nucu	2020	1990-2015	Income, energy prices, foreign investment.
Khribich et al.	2021	1995-2015	Social well-being indicators.
Marra and Colantonio	2021	1990-2015	Socio-technical factors analysis.
Camacho Ballesta et al.	2022	2001-2015	GDP per capita, foreign direct investment, trade openness, education index, life expectancy index, governance index.

In contrast, in a study (Marques et al., 2010) of 24 European Union countries between 1990 and 2006, lobbying activities of representatives of conventional energy sources (oil, coal and natural gas) and carbon dioxide emissions were identified among factors limiting RES development. However, income and the desire to reduce energy dependence were stimulants for RES

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use. Marinaş et al. (2018), in their study, considered the impact of economic growth on the share of renewable energy in the total energy consumption in the countries of Central and Eastern Europe from 1990 to 2014. Among other things, the study proved that in the long term, there is a bidirectional relationship between renewable energy consumption and economic growth for the entire group of countries included, as well as for the seven countries that were studied separately.

In turn, the contribution of renewable energy sources to the total primary energy supply (TPES) has been elucidated through a series of exogenous variables in the study (Papież et al., 2018). The research, covering the period 1995-2014, took into account a number of potential determinants of RES development relating to energy security, environmental well-being, economics and politics. It was proven that the most important factor influencing the development of RES is the local conditions of EU member countries and the distribution of major energy sources. It was emphasised that the countries with their own coal (Poland, the Czech Republic, Bulgaria, Estonia) and natural gas resources (the Netherlands, the UK, Romania, Hungary) had limited incentive to implement RES. With limited dependence on energy imports and the potential need for significant changes in the labour market, the authorities must take into account the political and economic risks arising from efforts to transform the energy mix. The study also identified other determinants that positively influence RES development, which included GDP per capita, the Shannon-Weiner Index (SWI), the concentration of energy supply, and the cost of fossil energy consumption relative to GDP. It was proven that per capita energy consumption has a disruptive effect on RES development. Akadiri et al. (2019), in a study of EU-28 countries covering the period 2007-2017, indicated a small effect of GDP per capita on the share of renewable energy in final consumption. Anton and Afloarei Nucu (2020) examined the impact of financial development on the share of renewables in total energy consumption in the EU-28 countries from 1990 to 2015. The study considered exogenous variables such as income, energy prices, financial development and foreign direct investment. As a result, it was found that all the isolated dimensions of financial development (banking sector, bond market and capital market) play a positive role in the aspect of increasing the share of RES in total energy consumption. At the same time, it was observed that for the new EU member states, the development of the capital market is not related to the level of RES consumption in total energy consumption. It was shown that renewable energy consumption is determined positively by energy prices and negatively by the level of economic development and foreign direct investment.

The study (Khribich et al., 2021) made an effort to determine the impact of social development on the share of renewable energy sources in total

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energy consumption in the short and long term in the European Union from 1995 to 2015. Based on the Social Development Index (SDI), constructed from several indicators of social well-being, a causal analysis was carried out according to the two-step Engle-Granger approach. The research proved a significant impact of social development on the share of RES in total energy consumption, but only in the long term. Marra and Colantonio (2020) proposed a study on the impact of socio-technical factors on renewable energy consumption in the total energy consumption between 1990 and 2015 in 12 the EU member states that are net energy importers: Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, the Netherlands, Portugal, Spain and Sweden. As a result, the positive impact of strict policies on renewable energy consumption, among other things, was proven, and it was also noted that public awareness is an insufficient factor in increasing RES.

The study (Camacho Ballesta et al., 2022) considered the impact of both economic and social determinants on the share of renewable energy sources in total energy consumption in the European Union from 2001 to 2015. The constructed model considered a number of exogenous variables, including GDP per capita, foreign direct investment, trade openness, education index, life expectancy index, and governance index. The study proved, on the one hand, the negative impact of economic factors and, on the other hand, the positive impact of social determinants on renewable energy consumption in the European Union.

Research methods

This article undertakes analyses of progress in the area of renewable energy. The focus is on assessing the impact of economic growth, energy efficiency, household final energy consumption and CO_2 futures on RES development. One element of the 7th Sustainable Development Goal, the share of renewable energy in gross final energy consumption, was chosen as a benchmark for RES development. The study was based on statistical data resources (Eurostat, 2022) and on the development of CO_2 emission futures (Investing, 2022), which were aggregated to annual average values. The period of study was taken as 2010-2020. In connection with the realisation of the research objective, a research methodology was formulated, the graphical visualisation of which is shown in Figure 2.

The evaluation of model inputs (explanatory variables) requires the determination of several evaluation criteria in the context of obtaining a satisfactory final result. One of them is the selection of variables for the model that is highly correlated with the explanatory variable and weakly correlated with each other (Gałecka & Smolny, 2018). The correlation analysis allows us

DOI: 10.34659/eis.2023.86.3.583

to determine how strongly variables are correlated with each other, which helps to establish whether regression is an appropriate method for data analysis. The strong correlation between explanatory variables and the dependent variable indicates that the regression model can predict values with high accuracy.

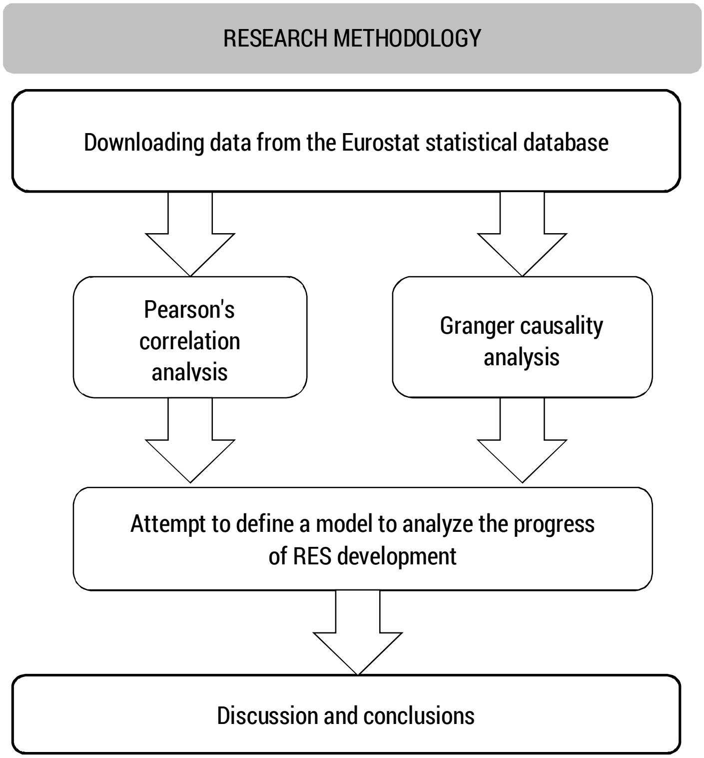

Figure 2. Research methodology

However, if such a relationship does not exist and there is a strong correlation between explanatory variables, the model may not be able to determine the correct contribution of each explanatory variable in the final equation. The linear correlation coefficient was calculated according to the formula (1) (a reference to the annexe) (Czaja & Preweda, 2000). The obtained correlation results are in the range [-1,1], where an absolute value close to 1 indicates a stronger linear relationship, while values close to 0 indicate its absence. Negative values specify that an increase in the variable X causes a decrease in the variable Y, while for positive values, an increase in X causes an increase in Y. We interpret the correlation thus obtained as follows (Kafle, 2019):

DOI: 10.34659/eis.2023.86.3.583

$0 < Correl < 0.4$ – low correlation,
$0.4 \leq Correl < 0.7$ – average correlation,
$0.7 \leq Correl < 1$ – high correlation,
$Correl = 1$ – a completely positive correlation.

In order to increase the accuracy of prediction, a causality test is also carried out to estimate whether the explanatory variable (X) is the cause of the explanatory variable (Y). Causality testing allows determining whether the history of changes in the explanatory variable helps to predict the dependent variable. Granger causality is particularly used for time series variables, where it is assumed that one variable affects another with a certain delay. Unlike correlation analysis, it allows determining which variable is the cause and which is the effect. For this purpose, we used causality in the sense of Granger (formulas: 2, 3) (Granger, 1969).

After obtaining the preliminary results of the analyses for selecting optimal explanatory variables, the final step was to acquire a preliminary model for analysing the progress of RES development, where an econometric multivariate regression model estimated by the least squares method was used for this purpose (formula 4) (Kuś & Pawlik, 2016). Two evaluation elements were used to estimate the accuracy of the model results. The first is the coefficient of determination, which reports what proportion of the variation in the value of the explanatory variable was explained by the estimated regression function (formula 5) (Sobczyk, 2007). For the second method of assessment, the coefficient of residual variation was used (formula 6) (Zimny, 2010).

To assess the correct specification of the model, the Ramsey RESET (Regression Equation Specification Error Test) test was applied, which allows for the evaluation of the correct form of the econometric model. This test is based on an expanded regression that includes the powers of the original regressors'. 3 predicted values from the original regression, as well as the powers of the original regressors (formulas: 7, 8) (Baum, 2006). If the test result is statistically significant, the originally obtained linear regression model is considered incorrect (the model omits significant variables).

Multivariate regression analysis allows us to show the relationship between multiple explanatory variables and the explanatory variable. For this purpose, 5 variables that can determine the increase in the share of RES were used for the initial determination of the model:

X_1 – gross domestic product (GDP),
X_2 – energy efficiency,
X_3 – final energy consumption in households,
X_4 – primary energy consumption,
X_5 – CO_2 emission futures contracts.

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The study assumed that the presented explanatory variables could have significantly influenced the development of RES in terms of all States of the European Union Community. Therefore, the following research hypothesis was adopted:

H1: It is possible to shape the share of energy from renewable sources (RES) in the total gross energy consumption using selected indicators.

Results of the research

Table 2 shows the values of the first step of the analysis, that is, the study of the interdependence between multiple variables and the share of RES in the gross final energy consumption for all the EU member states.

Table 2. Correlation results between the share of RES in gross final energy consumption and the series of variables X1-X5

COUNTRY	Correlationof Xn to Y (where n = 1,2,...,5)				
	X1	X2	X3	X4	X5
European Union (27)	-0.50	0.97	-0.61	-0.86	0.54
Belgium	-0.75	0.80	-0.61	-0.65	0.58
Bulgaria	-0.29	0.95	0.38	-0.13	0.50
Czechia	-0.17	0.88	-0.44	-0.84	0.33
Denmark	0.16	0.86	-0.68	-0.69	0.34
Germany	-0.78	0.97	-0.51	-0.90	0.61
Estonia	-0.12	0.84	-0.28	-0.43	0.52
Ireland	0.26	0.97	-0.49	0.03	0.65
Greece	0.35	0.63	-0.51	-0.95	0.50
Spain	-0.37	0.93	-0.72	-0.62	0.54
France	-0.58	0.93	-0.54	-0.86	0.54
Croatia	-0.24	0.77	-0.69	-0.79	0.33
Italy	-0.45	0.89	-0.62	-0.94	0.28
Cyprus	0.12	0.93	0.09	-0.35	0.68
Latvia	0.15	0.95	-0.51	0.03	0.38
Lithuania	-0.34	0.92	-0.06	0.25	0.21
Luxembourg	-0.54	0.87	-0.76	-0.49	0.67
Hungary	-0.31	-0.24	0.08	-0.83	-0.68
Malta	-0.28	0.56	0.89	-0.67	0.53
Netherlands	-0.56	0.83	-0.61	-0.81	0.74

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Austria	-0.78	0.83	-0.66	-0.79	0.47
Poland	-0.26	0.86	0.34	0.45	0.75
Portugal	-0.01	0.47	0.62	-0.27	0.36
Romania	0.35	0.75	-0.35	-0.80	-0.08
Slovenia	-0.56	0.56	-0.50	-0.84	0.23
Slovakia	-0.55	0.82	0.71	-0.35	0.72
Finland	-0.26	0.90	-0.10	-0.82	0.44
Sweden	-0.62	0.95	-0.91	-0.80	0.56

Source: authors' work based on statistical data.

The correlation results suggest that the main determinant of RES participation is energy efficiency, the results of which for most EU countries oscillate above 0.80, indicating a high correlation. Society's pursuit of sustainable development must be based on the use of energy that does not affect the environment, with a relatively strong correlation with energy efficiency (Fatona, 2011). Renovation of existing ones is one of the main aspects of energy efficiency in the EU, offering high potential for energy savings based on renewable energy production (Remeikiene et al., 2021). Buildings are responsible for 40% of total energy consumption in the European Union, so lower energy consumption with increased use of RES energy results in increased security of energy supply in EU member states (Directive, 2010). The impact of futures contracts on CO2 emissions is another element affecting the development of RES in the EU countries, but not necessarily a significant one. In most cases, it oscillates above 0.4, which may indicate a positive one-way correlation, where an increase in futures contracts determines an increase in RES participation. As for the Netherlands, Poland and Slovakia, a high correlation (above 0.7) was recorded. In the case of Hungary, a negative correlation value of as much as -0.68 was obtained, where the results differ significantly from the rest of the EU countries, where this correlation was positive. The impact of RES on household final energy consumption obtained a negative correlation in most countries. Such a result is in line with expectations, where the drive to reduce energy consumption follows the development of RES. A significant (negative) dependence was seen in particular for Spain, Luxembourg, and Sweden. Different results were obtained for, among others, Malta, Slovakia, and Portugal, where a study of the interdependence between the two factors showed a (significant) positive relationship. The study of the impact of GDP allowed us to conclude that the results of interdependence for most EU countries can be described as low and sometimes insignificant. Only Belgium, Germany and Austria showed a significant negative correlation of more than -0.7.

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Table 3. Results of causality analysis in the Granger sense for 1st order lags in the aspect of studying potential dependent variables towards causality of RES share in gross final energy consumption

COUNTRY	Causation of Xnto Y (where n = 1,2,…,5)									
	X1		X2		X3		X4		X5	
	F	*p*-value	F	*p*-value	F	*p*-value	F	*p*-value	F	*p*-value
European Union (27)	0.17	0.69	3.39	0.11	0.00	1.00	0.16	0.70	5.26	0.06
Belgium	0.59	0.47	0.07	0.80	0.00	0.97	0.83	0.39	9.04	0.02
Bulgaria	1.07	0.33	0.00	0.95	5.33	0.05	6.17	0.04	0.98	0.35
Czechia	1.51	0.26	0.72	0.43	0.02	0.90	0.17	0.69	2.17	0.18
Denmark	1.63	0.24	0.06	0.81	0.02	0.88	0.15	0.71	6.48	0.04
Germany	2.34	0.17	1.40	0.27	0.55	0.48	0.10	0.76	4.56	0.07
Estonia	0.17	0.69	1.00	0.35	0.95	0.36	5.75	0.05	0.68	0.44
Ireland	3.31	0.11	0.18	0.68	1.74	0.23	0.42	0.54	5.77	0.05
Greece	3.55	0.09	0.15	0.71	3.39	0.11	1.60	0.25	3.70	0.09
Spain	1.68	0.24	2.54	0.15	0.54	0.49	0.00	0.96	4.76	0.07
France	0.12	0.74	17.38	0.00	4.23	0.08	6.06	0.04	0.46	0.52
Croatia	0.00	0.96	4.85	0.06	4.43	0.07	0.10	0.76	4.25	0.08
Italy	0.42	0.54	5.02	0.06	1.36	0.28	1.30	0.29	2.01	0.20
Cyprus	0.03	0.87	2.01	0.20	1.05	0.34	0.07	0.80	0.04	0.86
Latvia	0.16	0.70	1.14	0.32	0.72	0.42	1.49	0.26	1.77	0.23
Lithuania	0.62	0.46	12.60	0.01	0.17	0.69	0.36	0.57	0.36	0.57
Luxembourg	0.11	0.75	1.81	0.22	2.60	0.15	0.01	0.92	0.42	0.54
Hungary	4.61	0.07	2.44	0.16	0.33	0.58	0.13	0.73	2.74	0.14
Malta	0.63	0.45	0.11	0.75	0.88	0.38	0.82	0.40	2.94	0.13
Netherlands	1.13	0.32	15.67	0.01	8.46	0.02	4.10	0.08	5.51	0.05
Austria	0.06	0.81	2.46	0.16	0.09	0.77	1.31	0.29	5.73	0.05
Poland	1.38	0.28	0.27	0.62	0.23	0.65	3.70	0.09	0.14	0.72
Portugal	0.13	0.73	3.63	0.09	0.38	0.56	1.39	0.28	0.56	0.48
Romania	2.90	0.13	0.24	0.64	0.31	0.60	1.04	0.34	0.12	0.74
Slovenia	0.06	0.81	2.10	0.19	2.71	0.14	0.94	0.36	5.77	0.05
Slovakia	0.09	0.77	1.31	0.09	0.02	0.90	0.17	0.69	2.39	0.17
Finland	0.95	0.36	2.70	0.14	0.00	0.98	0.21	0.66	0.00	0.99
Sweden	0.07	0.80	0.06	0.82	0.02	0.88	1.88	0.21	31.87	0.00

Source: authors' work based on statistical data.

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The results of the causality analysis in Table 3 identified the selected factors influencing the development of RES. Depending on the country, the number of factors meeting the *p*-value < 0.1 condition varied and most often involved between 1 and 2 values. In the case of Poland, variable X4 (primary energy consumption) was found to determine the growth of RES participation. Unfortunately, in the case of 7 member countries, no specific adjacency in the Granger sense was found for any of the analysed potential explanatory variables. This applies to the following countries: the Czech Republic, Cyprus, Latvia, Luxembourg, Malta, Romania and Finland. A conjunction of assumptions was used to determine the final model, i.e. those explanatory variables that had a high correlation with the explanatory variable (values above 0.7) and those with a *p*-value significance level below 0.1 (in terms of causality analysis) were included. The conjunction of these assumptions makes it possible to confirm the validity of hypothesis H1, where it was shown that during the studied period, there was at least one variable that determined the increase in the share of RES in the EU member states.

Table 4. Results of multivariate regression analysis for estimating a model of the share of RES in gross final energy consumption associated with the 7th Sustainable Development Goal for the European Union member states

COUNTRY	RESULTS				
	Model	R^2	V_e	*p*-value (coefficients)	VIF
European Union (27)	Y = 4.16*X2 – 14.361	0.95	0.03	X2 = 0.00; ~~X4,X5 > 0.05~~	-
Belgium	Y = -0.38*X1 + 2.83*X2 – 8.66	0.79	0.10	X1=0.05; X2 = 0.02; ~~X5 > 0.05~~	X1,X2 = 1.39
Bulgaria	Y = 20.41*X2 – 27.60	0.91	0.06	X2 = 0.00; ~~X3, X4 > 0.05~~	-
Czechia	Y = 2.99*X2 -0.76*X4 + 32.51	0.89	0.06	X2 = 0.01; X4 = 0.02	X2,X4 = 1.83
Denmark	Y = 1.60*X1 + 3.10*X2 – 16.65	0.93	0.07	X1=0.01; X2=0.00;~~X5 > 0.05~~	X1,X2 = 1.09
Germany	Y = -0.27*X1 + 2.43*X2 -5.88	0.98	0.03	X1=0.00; X2=0.00;~~X4,X5 > 0.05~~	X1,X2 = 1.69
Estonia	Y = 5.75*X2 + 2.94*X4 -6.16	0.85	0.04	X2=0.00; X4=0.02	X1,X2 = 2.73
Ireland	Y = 0.77*X2 -2.67	0.95	0.07	X2=0.00;~~ X5 > 0.05~~	-
Greece	Y = -1.46*X4 + 50.40	0.90	0.08	X4=0.00;~~ X1, X5 > 0.05~~	-
Spain	Y = 4.51*X2 -20.81	0.87	0.06	X2=0.00;~~ X3, X5 > 0.05~~	-
France	Y = 4.53*X2 + 0.02*X3 – 31.85	0.92	0.06	X2=0.00; X3 = 0.05; ~~X4 > 0.05~~	X2,X3 = 2.19
Croatia	Y = 5.14*X2 + 0.06*X3 -5.47*X4 + 8.58	0.93	0.02	X2=0.00; X3=0.01; X4=0.01; ~~X5 > 0.05~~	X2 = 4.25 X3 = 3.66 X4 = 4.63
Italy	Y = 0.22*X4 +50.34	0.88	0.06	X4=0.03; ~~X2 > 0.05~~	-
Cyprus	Y = 6.51*X2 -36.39	0.86	0.13	X2=0.00	-

DOI: 10.34659/eis.2023.86.3.583

Latvia	Y = 7.77*X2 + 2.78	0.91	0.03	X2=0.00	-
Lithuania	Y = 6.29*X2 -4.57	0.85	0.04	X2=0.00	-
Luxembourg	Y = 1.62*X2 – 4.01	0.78	0.25	X2=0.02; ~~X3 > 0.05~~	-
Hungary	y = -1.05*X4 + 39.04	0.69	0.06	X4=0.00; ~~X1 > 0.05~~	-
Malta	Y = 0.17*X3 -25.26	0.78	0.26	X3=0.00	-
Netherlands	Y = -0.55*X4 + 0.19*X5 +39.96	0.90	0.12	X4=0.00; X5=0.00; ~~X3,X2 > 0.05~~	X2,X3 = 1.13
Austria	Y = -0.30*X1 + 2.21*X2 + 12.93	0.97	0.02	X1=0.00; X2=0.00; ~~X4,X5 > 0.05~~	X1,X2 = 1.14
Poland	Y = 3.93*X2 + 0.12*X5 -5.73	0.89	0.07	X2=0.00; X5=0.01; ~~X4 > 0.05~~	X2,X5 = 1.02
Portugal	Y = 5.83*X2 -14.33	0.22	0.11	X2=0.05	-
Romania	Y=0.82*X2 -0.48*X4 +35.48	0.84	0.02	X2=0.01; X4=0.01	X2,X4 = 1.22
Slovenia	Y = -3.34*X4 + 44.31	0.74	0.03	X4=0.01; ~~X5 > 0.05~~	-
Slovakia	Y = 4.44*X2 + 0.03*X3 – 20.21	0.94	0.07	X2=0.00; X3=0.02; ~~X5 > 0.05~~	X2,X3 = 1.07
Finland	Y = 12.37*X2 -31.46	0.81	0.04	X2=0.00; ~~X4 > 0.05~~	-
Sweden	Y = 5.53*X2 +7.40	0.91	0.04	X2=0.00; X3,~~X4,X5 > 0.05~~	-

Source: authors' work based on statistical data.

Table 4 shows the results obtained from the analysis of the share of RES in gross final energy consumption in terms of the 27 countries of the European Union. The values of the coefficient of determination (R_2), which indicates the accuracy of the model's fit to the data, were above 0.80 for most countries. This means that 80% of the variability of the dependent variable is explained by the applied regression model. Lower results of this coefficient were obtained for Portugal, Hungary, Slovenia, Luxembourg, and Malta. As for the coefficient of residual variation (V_e), which determines the average value of the residual error, its value was less than 10% for 23 countries, which represents 82% of all countries examined and has high coverage with the results of the coefficient of determination. Estimation of the VIF point made it possible to determine whether there is evidence of collinearity of the explanatory variables. For most countries, variable Y was explained by only one parameter, X; therefore, no VIF was calculated for these countries. In the remaining cases, values below 2 predominate, suggesting that data collinearity was not obtained. Croatia had higher values (X2 = 4.25, X3 = 3.66, X4 = 4.63), but according to the "rule of thumb" (the upper endpoint of VIF is values above 5), the results do not seem to suggest that there is evidence of collinearity (Marcoulides & Raykov, 2018). The authors note that only those variables with a *p*-value less than 0.05 were included in the final model. If this value was exceeded, the variables were not included in the model, which is presented in Table 4 as crossed-out values. In order to determine the qual-

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ity of the model, Table 4 also includes the results of the coefficient of determination (R_2) and the coefficient of residual variation (V_e). Two assumptions were made for the final analysis determining the high performance of the model:

- The value of the coefficient of determination must not be less than 0.9 to consider the model as very good (Aczel & Sounderpandian, 2018).
- A cutoff level of 10% or 15% is assumed for the residual coefficient of variation (Ręklewski, 2020). In the case of the present study, a value of no less than 10% was assumed.

The conjunction of these assumptions allows us to assume that the obtained model may be correct. Relating the assumptions made to the results presented in Table 4, it was found that for 11 countries, satisfactory model results were obtained for analysing the progress of RES development. This includes the following countries: Bulgaria, Denmark, Germany, Ireland, Greece, France, Croatia, Latvia, Austria, Slovakia and Sweden.

In the final step, a diagnostic test was conducted to check whether the obtained regression models were properly defined and contained the appropriate number of explanatory variables. Table 5 presents the results of the RESET test for the models that were determined to be correct.

Table 5. RESET test results for the obtained models

COUNTRY	RESET TEST	Model linearity
Bulgaria	RESET = 0.05, *p*-value = 0.95	YES
Denmark	RESET = 2.54, *p*-value = 0.16	YES
Germany	RESET = 4.77, *p*-value = 0.08	YES
Ireland	RESET = 20.57, *p*-value = 0.01	NO
Greece	RESET = 0.06, *p*-value = 0.95	YES
France	RESET = 0.70, *p*-value = 0.63	YES
Croatia	RESET = 1.29, *p*-value = 0.59	YES
Latvia	RESET = 1.71, *p*-value = 0.25	YES
Austria	RESET = 1.58, *p*-value = 0.34	YES
Slovakia	RESET = 1.88, *p*-value = 0.28	YES
Sweden	RESET = 1.45, *p*-value = 0.26	YES

Source: authors' work based on statistical data.

The RESET test confirmed the validity of regression analysis results in 10 cases where explanatory variables were properly selected. However, in the case of Ireland, the test indicated an incorrect model, where the squares of

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explanatory variables improved the explanation of the dependent variable, suggesting that the originally obtained model was underestimated and did not include a sufficient number of variables.

Discussion and Conclusions

The research conducted in the study proved the differential impact of selected factors on the development of RES. In all the EU member states, at least one of the proposed explanatory variables determined the increase in the share of RES in gross final energy consumption, which allowed positive verification of the proposed research hypothesis. The results of the correlation tests made it possible to determine which of the proposed variables are significantly statistical from the point of view of the share of RES in gross final energy consumption. The key determinant of the final model turned out to be the parameter X2 – energy efficiency, which, in combination with the results of the New York State Energy Development study, testifies to the high potential of energy efficiency and renewable energy (NYSERDA, 2014). Only in the case of Greece, the X2 parameter did not prove to be a key factor, which may be dictated by the country's low attention to energy conservation in terms of relevant sectors: transportation and buildings (Zervas et al., 2021). For Greece, the main factor determining the development of RES participation is the declining consumption of primary energy. It should be borne in mind that the greenest energy is that which does not need to be produced, i.e. saved by increasing energy efficiency. In the case of Poland, unfortunately, the coefficient of determination was lower than the required assumption by 0.01, which resulted in the lack of validity of the model to analyse the progress of RES development. In the case of Poland, two variables are noteworthy: energy efficiency and CO_2 futures. In the case of the former, the correlation score was 0.86, which may be an aftermath of the drive towards decarbonisation and the consistent development of RES (Amcham, 2022). Similarly, Sowa (2018) stated in his considerations determining the essence of the impact of renewable energy sources on improving energy efficiency. On the other hand, in the case of CO_2 futures contracts, a result of 0.75 was obtained, where such a result may be due to the implementation of, among other things, the 'My Current' program, which encouraged investment in renewable energy, where in 2019-2020, thanks to it, about 400 thousand prosumer installations mainly based on photovoltaics were built (Olczak et al., 2021). Another Polish researcher made a similar finding, determining that trading in CO_2 emission rights allows better use of funds for green investments (Olkuski, 2015). Noteworthy is the case of Hungary, where the correlation results are negative for both variables in question, which is not found

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for any of the other EU member states. Meeting energy needs is an ever-present problem in Hungary, regardless of climate change, due to the country's heavy reliance on oil and gas imports (Szlavik & Csete, 2012).

The analysis of the research showed that the share of Gross Domestic Product for most EU member states does not show a direct correlation in terms of RES development, which is also confirmed by the study of another team of researchers (Szustak et al., 2022). The authors found that changes in electricity production, regardless of the source, do not directly affect the value of GDP and that stronger correlations in some countries compared to other EU countries suggest a random dependence. Similarly, this was also found in the study by Marques et al. (2010), showing that economic growth in selected countries hinders the process of renewable energy production. In the case of the study by Akadiri et al. (2019), a small impact of per capita GDP on the share of renewable energy in final consumption was also demonstrated. Camacho Balesta et al. (2022) argued that a similar situation is caused by high economic growth, which results in an increased demand for energy that cannot be immediately satisfied from renewable sources. However, it should be borne in mind that different results may appear in the literature, where correlations between GDP and energy consumption. In a study by Marinas et al. (2018) it was noted that a 1% increase in GDP leads to an increase in interest in alternative energy sources by 0.32%. However, as stated (Karanfil, 2009), this may be due to the research period chosen. The quoted statements of the researchers are confirmed by the results of the causality study, where no significant correlations were obtained between the impact of GDP on the increase in the share of RES in gross final energy consumption. Only in the case of Greece and Hungary were results obtained that may show some connection between the two. Menegaki (2011) presented a similar position, where empirical results did not confirm a causal relationship between renewable energy consumption and GDP, although panel causality tests reveal short-term relationships between renewable energy and greenhouse gas emissions and employment.

The applied causality analysis in the sense of Granger showed a significant impact of futures contracts on CO_2 emissions in terms of RES development, where such a result is also confirmed by the study of Rahman et al. (2022). The authors found a bidirectional causal relationship occurring between renewable energy and CO2 emissions. Similar insights were obtained by another team of researchers (Dong et al., 2021), focusing their analysis on 30 Chinese provinces, where the impact of renewable energy development on CO_2 efficiency was determined. The study's findings correspond with the EU's 'Fit for 55' package aimed at reducing greenhouse gas emissions by at least 55% by 2030 and achieving climate neutrality by 2050 in the EU. The package points to the need for a comprehensive overhaul of

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the EU Emissions Trading Scheme (ETS) currently in operation (Rada Europejska & Rada Unii Europejskiej, 2022), which should result in, among other things, the development of RES.

The deep transformation of the energy system involves replacing fossil fuels by using renewable energy and dramatically increasing energy efficiency (Kaygusuz et al., 2007). The study presented here made it possible to confirm how high an interdependence exists between these aspects for most EU member states. The research results obtained are also justified by the EU's stringent renewable energy and energy efficiency targets (Kettner & Kletzan-Slamanig, 2020). In 2022, under the conditions of Russia's military aggression against Ukraine and the resulting disruption of the global energy system, the aforementioned areas again became the subject of discussion by the EU leaders. The European Commission proposed the REPowerEU plan to make the EU independent of Russian energy supplies by 2030. It was proposed to increase the target for the share of renewable energy in total consumption to 45% by 2030 (European Commission, 2022). In September 2022, MEPs voted in favour of this target. In a separate vote, they also backed a law setting new energy efficiency improvement targets of reducing final energy consumption by at least 40% by 2030 and 42.5% in primary energy consumption compared to 2007 projections. Achieving these targets requires binding national contributions to be set at the level of individual member states (Parlament Europejski, 2022). In this context, it should be borne in mind that the capabilities of the individual EU economies in the aspect of RES development vary due to their specificities (Firlej & Stanuch, 2022), which may result, for example, from their geographical location. The implementation of ambitious goals in the area of energy efficiency improvement and RES development requires the solidarity commitment of all EU member states. In the context of the aforementioned goals, the declarations on the effects of energy and climate policy made by the EU member states in their National Energy and Climate Plans seem insufficient and need to be verified. In the new geopolitical conditions, ensuring energy security and moving away from imports of conventional energy resources from Russia is a strategic task that determines further socio-economic development. Increasing energy efficiency and investing in clean energy technologies will support environmental well-being.

The results obtained in this study provide support for decision-making in the area of energy policy in selected European Union member states, for which the constructed models have proven to be correct. These models determine the degree of influence of selected factors on renewable energy consumption, which, combined with the knowledge of political decision-makers about local energy security aspects, possible energy supply dependen-

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cies, and labour market conditions, can be helpful in the decision-making process in individual countries.

In particular, an energy policy aimed at increasing energy efficiency can influence the growing interest in consuming energy from renewable sources. The growth in energy efficiency of the economy leads to a decrease in the overall energy demand, which creates greater opportunities for utilising renewable energy sources to meet energy needs, as well as reducing the costs associated with their use. A policy that supports energy efficiency, therefore, determines an increase in the competitiveness of renewable energy sources compared to conventional energy sources. A holistic approach to energy efficiency and unconventional energy sources within the implemented energy policy should significantly contribute to the reduction of greenhouse gas emissions and the improvement of the natural environment's well-being. It is worth noting the possibility of combining supportive instruments for both aspects, as exemplified by subsidies and tax incentives for the thermal modernisation of residential buildings and the installation of photovoltaic panels.

The policy regarding CO_2 emissions trading should be characterised by stability and predictability over a long time horizon. This will provide economic entities with confidence in the viability of conducting research and development activities and making investments in the renewable energy sector in the long term. High prices of CO_2 emission contracts reduce the economic profitability of using conventional energy sources, thereby enhancing the attractiveness of production and consumption of energy from renewable sources. This situation supports an increase in investment expenditure on infrastructure used for renewable energy production. Consequently, the supply and consumption of energy from renewable sources increase. The popularity and attractiveness of conducting research and development activities also grow, implying the creation of modern and more efficient technological solutions used in the process of renewable energy production.

The article proposes a model for RES development based on a set of determinants not simultaneously considered together in previous studies. In particular, the conclusions of studies on the role of energy efficiency (to a greater extent) and carbon contracts (to a lesser extent) in the process of RES development may inspire an attempt to construct further models of this type enriched with additional determinants in individual member states of the European Union. It seems that this type of research will require considering factors closely related to local conditions of renewable energy development, which may be associated with, among others, dependence on energy resource imports or geographical location. Prospects for future research should not be limited to modelling RES development with selected variables but should also take into account their sectoral structure, including electricity, heating and cooling, and transportation.

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Like all research, this study also has certain limitations. First of all, the study uses only selected variables affecting RES development, which was partly determined bythe data availability. Secondly, the study covers only member countries of the European Union, which, due to the characteristics of its economy, has limited applicability to the rest of the world.

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The contribution of the authors

Conceptualization, K.A.F.; methodology, K.A.F. and M.S.; obtaining data, M.S.; literature review, K.A.F.; estimation of models, M.S.; analysis and interpretation of data, M.S.; writing – original draft preparation, K.A.F. and M.S.; project administration, K.A.F.; funding acquisition, K.A.F. and M.S.

All authors have read and agreed to the published version of the manuscript.

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Annex 1. List of math formulas

1. The linear correlation coefficient:

$$Correl(X,Y) = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i-\bar{y})^2}}, \tag{1}$$

2. Granger causality:

$$Yt = a_0 + \sum_{i=1}^{p} ay_i\, Yt - i + \sum_{i=1}^{p} ax_i\, Xt - i + \varepsilon Yt, \tag{2}$$

$$Xt = \beta_0 + \sum_{i=1}^{p} \beta x_i\, Xt - i + \sum_{i=1}^{p} \beta y_i\, Yt - i + \varepsilon Xt, \tag{3}$$

where:
Y_t, X_t – study variables,
α_0, β_0 – free world,
p – row of delays.

3. A regression model:

$$Y = a_0 + a_1X_1 + a_2X_2 + \cdots + a_kX_k + \varepsilon, \tag{4}$$

where:
X_1, X_2, X_k – explanatory variables,
a_0, a_1, a_k – the values of the coefficients of the model parameters,
ε - random error.

4. The coefficient of determination:

$$R^2 = \frac{\sum_{t=1}^{n}(\hat{y}_t - \bar{y})^2}{\sum_{t=1}^{n}(y_t - \bar{y})^2}, \tag{5}$$

where:
y_t – the actual value of the dependent variable,
$\hat{y}_t$ – the predicted value of the dependent variable,
$\bar{y}$ – the mean value of the actual dependent variable.

5. The coefficient of residual variation:

$$V_e = \frac{S_e}{\bar{y}_t} * 100\%, \tag{6}$$

where:
V_e – the actual value of the dependent variable,
S_e – the standard deviation of the residual component,
$\bar{y}_t$ – the arithmetic mean of the values of the *y* variable.

6. The Ramsey Regression Equation Specification Error Test (*RESET*):

Step I: calculation of the standard linear regression model – formula (4).

Step II: calculation of theoretical values:

$$\hat{Y} = \hat{a}_0 + \hat{a}_1 X_1 + \hat{a}_2 X_2 + \cdots + \hat{a}_k X_k, \tag{7}$$

Step III: consideration of the model extended by squares and products of theoretical values $\hat{Y}$:

$$Y = \gamma_0 + \gamma_1 X_1 + \cdots + \gamma_k X_k + \gamma_k + 1\hat{Y}^2 + \gamma_k + 2\hat{Y}^3 + \varepsilon. \tag{8}$$

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