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RENEWABLE ENERGY PRODUCTION AND THE SOCIO-ECONOMIC DEVELOPMENT OF REGIONS – A CASE STUDY OF POLAND

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ABSTRACT: The present study was undertaken to analyse and evaluate energy production from renewable energy sources in the context of the socio-economic development of Polish regions. The aim of this study was to evaluate renewable energy production in Polish voivodeships and to determine the relationship between renewables and the socio-economic development of Polish regions. The research objective was achieved with the use of agglomerative hierarchical clustering and linear ordering methods. These techniques were applied to rank Polish voivodeships in terms of renewable energy production and to determine the links between the socio-economic development of Polish regions and renewables. Long-term changes in the analysed parameters were assessed based on data for 2017 and 2022. The analysis revealed considerable differences in renewable energy generation across Polish voivodeships, as well as the presence of a negative relationship between green energy and socio-economic development, which can be attributed to the specificity of Polish regions. The development of renewable energy production undoubtedly poses a significant challenge for Poland, and further efforts are needed to fully harness the country's renewable energy potential. However, positive changes have been observed in the least developed Polish voivodeships, which can contribute to an improvement in the welfare of all Polish citizens in the future.

KEYWORDS: renewable energy sources, socio-economic development, regional policy

Introduction

The growing scarcity of fossil fuels increases global energy costs, contributes to adverse climate change, and poses one of the greatest challenges to global economic growth (Pultowicz, 2009; Zhang, 2024; Sułek & Borowski, 2024; Cai, 2025). These problems can be attributed mainly to globalisation and economic interdependence between countries, as well as to market processes and institutional changes that were initiated at the end of the 20th century. In this context, the global economy is also affected by the steady growth of national economies, innovation, foreign investments, and the resulting increase in population and demand for energy (Oatley, 2022; Tomizawa et al., 2020; Wallerstein, 2023; Baloch et al., 2021). These processes have contributed to the depletion of conventional energy sources and the degradation of the natural environment, but at the same time, technological progress has enabled humanity to harness the potential of renewable energy sources (RES). In recent decades, numerous efforts have been made to move the energy system away from fossil fuels to RES, and this transition is expected to resolve the above problems.

The present study was undertaken to examine the extent to which renewable energy production creates opportunities for socio-economic growth in Polish regions. In this context, the aim of this study was to evaluate renewable energy production in Polish voivodeships and to determine the relationship between renewables and the socio-economic development of Polish regions.

The research objective was achieved with the use of agglomerative hierarchical clustering and linear ordering methods. These techniques were applied to rank Polish voivodeships in terms of renewable energy production and to determine the links between the socio-economic development of Polish regions and renewables. Long-term changes in the analysed parameters were assessed based on data for 2017 and 2022.

An overview of the literature

Nowadays, many studies on renewable energy sources refer to the assessment of the opportunities and possibilities they offer in comparison to traditional energy sources. As some authors indicate, renewable energy has many advantages because it is non-depletable, more environmentally-friendly, and easy and cheap to utilise. Renewables decrease a country's dependence on energy imports, contribute to employment in innovative energy companies, and promote economic development in areas affected by depopulation (Guangul & Chala, 2019; Domac et al., 2005). Renewables also enable countries to diversify their energy sources and achieve energy independence (Kamprowski, 2021; Olczak, 2020).

It should also be noted that for several decades, the above problems have been addressed by sustainable development policies. Sustainable development has been defined as an approach to growth and development (of countries, territorial governments, businesses, institutions, etc.) that meets the needs of the present generations without compromising the ability of future generations to meet their own needs (Pezzey, 1992; Chichilnisky, 1999). Therefore, sustainable development combines environmental, social, and economic dimensions (Moldan et al., 2012). Strategies and policies aiming to popularise RES are being adopted in many countries and regions of the world. According to estimates, 50% of the world's electricity should come from renewable energy by 2050 (Svenfelt et al., 2011).

The economic aspects of the transition from conventional fuels to RES have been analysed in numerous studies. Researchers have examined the economic consequences of RES popularisation, the potential improvement in the economic performance of countries due to the use of RES, and the methods for measuring the effectiveness and cost of innovative solutions.

In many studies, energy problems and the applicability of RES have been analysed as determinants that can contribute to the achievement, maintenance, or improvement of economic growth. However, research findings concerning the presence and strength of associations between the use of RES and GDP are often ambiguous (Saidi, 2024). In recent years, most researchers have concluded that in the European Union (EU), economic growth is positively correlated with RES, in particular in the long-term perspective (Ntanos et al., 2018; Alper & Oguz, 2016; Armeanu et al., 2017). In their opinion, the higher the level of economic development, the greater the use of RES, and vice versa.

Renewable energy projects can create new jobs and stimulate local economies, thus contributing to sustainable socio-economic development of the entire country (Babuchowska & Marks_Bielska, 2017; Rio & Burguillo, 2009; Dvorak et al., 2017; Gonda, 2011; Stanowicka, 2025). In Poland, territorial governments and local authorities play a significant role in promoting and supporting the development of RES by adopting local energy strategies, creating a favourable environment for investments in green energy, and implementing renewable energy projects, thus facilitating the energy transition on their territory (Frankowski, 2017; Cheung et al., 2019).

The conditions for harnessing energy from renewable resources also differ across regions, which is why they should be studied locally (regions differ in renewable energy performance due to local variations in factors such as isolation and average wind speed). Renewable energy should promote the growth of less developed regions which are abundant in RES (Zborowska, 2016; Schneider et al., 2007). It can also contribute to the implementation of a higher number of innovative solutions (including eco-innovative technologies), job creation, and stimulation of market competitiveness, thus delivering economic, social, and environmental benefits to regions in line with sustainable development principles (Pietrzyk-Sokólska et al., 2016).

Conventional fuels still dominate in Poland's energy mix, and coal is the main source of energy. At the beginning of 2024, 53% of electricity was derived from bituminous and brown coal, 16.5% was generated from other conventional fuels, and around 30% of electricity was derived from RES (Energy Market Agency, 2024). In many respects, excessive dependence on a single energy source is undesirable due to the risk of power outages and supply chain disruptions caused by political or economic instability in the world. Coal burning also exerts a negative impact on human health and the natural environment (Pietrzak et al., 2016).

In Poland, the transition to clean energy began relatively recently. Between 2005 and 2022, wind energy and solid biomass, including biomass co-firing, were the leading sources of renewable energy.

Coal remains a relatively cheap source of energy in Poland, and financial considerations often take precedence over environmental issues. Recent years have witnessed considerable improvement in the socio-economic status of Polish voivodeships, but much remains to be done to promote sustainable development based on RES in Polish regions (Dzikuć et al., 2021).

Research methods

The aim of the present study was to determine energy production from RES in Polish regions and to evaluate the relationship between renewable energy generation and the socio-economic development of Polish voivodeships. The research objective was achieved with the use of agglomerative hierarchical clustering and linear ordering methods.

The methods of multidimensional comparative analysis are used to compare objects described by a set of unique characteristics. These techniques are deployed to analyse the examined objects and describe their key properties (Panek, 2009). This study relied on agglomerative clustering, which belongs to hierarchical grouping methods. Objects were grouped in clusters using Ward's method. The analysed variables should be characterised by high variance and the absence of collinearity. The presence of very strong correlations between variables may undermine the creation of meaningful clusters (Stanisz, 2007).

Agglomerative hierarchical clustering methods were applied to determine electricity generation from RES in Polish voivodeships. The following variables were used in the analysis: WO – electricity generated by hydropower plants per 100,000 population; WIL – electricity generated by windfarms per 100,000 population; PVA – electricity generated by photovoltaic power stations per 100,000 population; BG – electricity generated by biogas plants per 100,000 population; BM – electricity generated by biomass plants per 100,000 population.

An initial analysis demonstrated that the coefficients of variation exceeded the minimum preset value of 10%. The strength of relationships between variables was determined by calculating Pearson's correlation coefficients (r). The variable describing the amount of electricity generated by biomass plants was eliminated due to a strong correlation with the electric output of photovoltaic power plants. Data were normalised with the use of a standardisation procedure.

In the next step, Polish voivodeships were arranged in a linear order based on renewable energy production and the levels of socio-economic development. The following variables were used to assess the socio-economic development of Polish regions:

1. Demographic changes: D1 – natural population growth per 1000 population, D2 – net migration rate per 1000 population, D3 – dependency ratio (number of dependents per 100 working-age population), D4 – live births per 1000 population.
2. Employment: L1 – registered unemployment (%), L2 – employment in the working-age population (18-59/64 years) (%), L3 – economic activity rate (%), L4 – average gross monthly remuneration relative to the national average (% Poland = 100).
3. Social integration: S1 – at-risk-of-poverty rate (% households), S2 – proportion of population receiving welfare benefits (% population), S3 – average monthly disposable income per capita (PLN), S4 – university graduates per 10,000 population (number of individuals).
4. Economic potential: G1 – gross domestic product per capita (%), G2 – value of investments per capita (PLN), G3 – gross fixed capital formation per capita (Poland = 100), G4 – number of businesses entered into the official business register (REGON) per 10,000 population.
5. Innovation: I1 – share of innovative enterprises in the total number of enterprises (%), I2 – number of patents granted by the Polish Patent Office per 10,000 population, I3 – share of R&D personnel in the overall workforce (%), I4 – share of innovation-active industrial enterprises in the total number of enterprises (%).
6. Local government finance: F1 – total revenue per capita (PLN), F2 – share of own-source revenue in total revenue (%), F3 – European Union funding for local programs and projects per capita (PLN), F4 – share of investment expenditure in total expenditure (%).

A multi-criteria classification method was applied to rank Polish voivodeships in a linear order based on diagnostic variables. Only diagnostic parameters with the required level of variance were selected for the analysis. The minimum value of the coefficients of variation for renewable energy production was set at 10%. All five variables (WO, WIL, PVA, BG, BM) were included in the analysis. All variables are stimulants. The coefficients of variation for parameters D3, D4, L2, L3, L4, S3 and F4 were below 10%, and they were eliminated from the analysis of the socio-economic development of Polish voivodeships. In the group of variables used in further analysis, parameters D2, L1, and S1 are destimulants. All variables were normalised before the linear ordering procedure. Data were processed statistically in the Statistica PL program.

The values of the studied parameters were compared in 2017 and 2022. Statistical data for these years were readily available, and they were used to evaluate changes in the analysed variables over a period of five years. Data were acquired from the Local Data Bank of Statistics Poland (Statistic Poland, 2024) and the reports of the Energy Regulatory Office (Energy Regulatory Office, 2024).

Results of the research

Renewable energy production in Polish voivodeships was evaluated in the first stage of the analysis (Table 1).

The data presented in Table 1 indicate that the amount of electricity generated by hydropower plants (variable WO) was lowest in the Lublin voivodeship. In half of the Polish voivodeship, the output of hydropower plants did not exceed 1 megawatt (MW) per 100,000 population. Western Pomerania and Świętokrzyskie were the leading voivodeships in terms of electricity generated by windfarms and biomass plants. Between 2017 and 2022, the energy output of windfarms increased by 61.53% in Western Pomerania and by 44.05% in Poland. In the analysed period, the greatest increase in renewable energy production was noted in photovoltaic power stations, and Świętokrzyskie emerged as the leading voivodeship in this respect. In Poland, solar power output per 100,000 population increased by 35.89 MW between 2017 and 2022. In 2022, no energy was generated by solar power plants and biomass plants in Lesser Poland. Lesser Poland was also the only Polish region to experience a drop in wind power generation in 2022. In the analysed period, hydropower output decreased in nine voivodeships.

Table 1. Variables describing energy generation from renewable energy sources (RES) in Polish voivodeships in 2017 and 2022

Specification	2017					2022				
	WO	WIL	PVA	BG	BM	WO	WIL	PVA	BG	BM
Lower Silesian	2.55	6.08	0.12	0.76	3.46	2.93	10.50	7.53	0.74	3.85
Kuyavian-Pomeranian	10.20	28.67	0.39	0.77	8.51	10.46	38.72	9.73	0.91	8.83
Lublin	0.07	6.53	1.45	0.65	0.12	0.05	7.16	8.37	0.79	0.13
Lubusz	11.60	18.88	0.33	0.49	0.18	11.62	24.95	29.42	0.85	0.35
Łódź	0.46	23.49	0.09	0.51	2.39	0.44	27.29	7.02	0.67	2.49
Lesser Poland	5.67	0.20	0.27	0.32	0.09	5.43	0.17	0.00	0.34	0.00
Masovian	0.41	7.18	0.04	0.55	5.06	0.40	7.69	3.63	0.56	3.27
Opole	3.11	13.95	0.09	0.39	0.00	3.76	15.67	7.39	0.46	0.00
Subcarpathian	9.83	7.18	0.21	0.39	2.74	10.06	7.36	4.57	0.45	0.14
Podlaskie	0.07	16.63	1.07	1.04	7.14	0.05	18.59	20.49	1.24	1.24
Pomeranian	1.47	29.83	0.11	0.98	0.10	1.23	52.60	13.58	1.11	0.10
Silesian	0.81	0.73	0.20	0.47	1.98	0.83	2.54	1.01	0.51	2.08
Świętokrzyskie	0.23	1.80	0.04	0.17	19.13	0.19	2.25	904.39	0.33	20.64
Warmian-Masurian	1.20	24.71	0.55	1.03	2.05	1.05	38.26	17.24	1.53	2.07
Greater Poland	0.36	20.03	0.19	0.70	3.34	0.35	29.11	14.26	0.93	6.64
West Pomeranian	0.79	87.31	0.22	1.01	4.88	0.82	141.02	16.38	1.21	5.46

Source: authors' work based on (Energy Regulatory Office, 2024) using Statistica PL.

The indicators describing the socio-economic development of Polish voivodeships are presented in the Supplementary Materials. The indicators for 2017 and 2022 are presented in Tables 2 and 3, respectively. Table 4 contains basic descriptive statistics relating to energy generation from the examined RES in 2017 and 2022. These data were used in successive stages of the analysis.

The greatest increase in the average values of the analysed variables was noted in electricity generated by photovoltaic power stations per 100,000 population (PVA). The average solar power output per 100 population increased nearly 80-fold between 2017 and 2022. The average energy output of biomass plants decreased by around 5% in the studied period. High values of the coefficients of variation in the analysed variables point to significant differences across Polish voivodeships in both 2017 and 2022. Skewness values were positive, and the distribution of variables relating to renewable energy production was right-skewed. In most voivodeships, electricity production from renewables was below the average in the analysed period.

For agglomerative hierarchical clustering to produce reliable results, the examined variables may not be strongly correlated. Pearson's correlation coefficients were calculated for the variables in Table 1. In 2022, the coefficient of correlation between variables PVA and BM reached 0.864 (Table 1), whereas the coefficients of correlation between the remaining variables did not exceed 0.6. Therefore, the energy output of biomass plants (BM) was eliminated from the set of variables describing renewable energy production.

Polish voivodeships were grouped into clusters based on the values of four variables (WO, WIL, PVA, and BG) using Ward's method. Six clusters of voivodeships were formed based on the data for 2017 and 2022. The results are presented in Table 5.

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Table 2. Indicators of the socio-economic development of Polish voivodeships in 2017

Specification	D1	D2	L1	S1	S2	S4	G1	G3	G4	I1	I2	I3	I4	F1	F2	F3
dolnośląskie	-1.25	0.96	5.7	11.0	4.1	120	57012	119.3	1271	14.8	8.9	1.2	15.23	1258.7	58.4	44.9
kujawsko-pomorskie	-0.17	-0.63	9.9	14.4	8.0	82	41779	77.4	940	12.1	4.3	0.8	12.68	1690.7	46.0	31.5
lubelskie	-1.19	-2.22	8.8	18.4	6.6	100	35935	53.2	834	14.1	7.5	1.0	13.81	1438.5	37.2	40.6
lubuskie	0.01	-0.94	6.5	12.8	6.5	39	42701	96.7	1110	13.0	2.1	0.5	12.00	2500.0	48.5	51.2
łódzkie	-2.98	-0.72	6.7	7.2	5.6	85	48226	94.5	993	12.7	8.0	0.9	12.23	1374.2	52.8	25.3
małopolskie	1.86	1.21	5.3	20.9	4.8	158	47047	77.8	1121	15.1	9.7	1.9	17.30	930.1	47.4	32.1
mazowieckie	0.86	2.52	5.6	10.0	4.8	131	82208	176.7	1503	16.8	11.6	2.3	15.25	657.3	60.2	24.9
opolskie	-1.81	-1.23	7.3	9.6	4.7	78	41040	86.7	1016	12.6	6.2	0.5	17.52	3369.2	50.4	35.2
podkarpackie	1.22	-0.84	9.6	21.7	7.8	78	36024	63.9	803	15.3	4.4	1.0	15.90	1639.2	36.6	44.8
podlaskie	-0.40	-1.44	8.5	22.4	7.3	84	37297	60.0	854	12.2	2.3	0.7	13.18	1856.3	41.9	33.5
pomorskie	2.51	1.55	5.4	9.7	5.9	113	49798	90.7	1264	15.5	5.6	1.1	15.14	1428.3	50.2	24.8
śląskie	-1.41	-0.93	5.1	7.5	3.8	84	53449	108.5	1033	14.3	7.7	0.8	15.02	1809.6	55.2	24.7
świętokrzyskie	-2.73	-1.78	8.8	16.4	7.6	69	37134	64.1	900	12.2	3.4	0.4	15.80	4270.3	39.6	37.8
warmińsko-mazurskie	0.08	-1.91	11.7	20.7	9.6	67	36449	56.6	874	9.1	2.9	0.6	11.17	1959.6	40.9	34.7
wielkopolskie	2.06	0.33	3.7	15.5	5.1	105	56448	107.3	1210	13.8	6.7	0.9	15.13	1609.6	50.0	22.5
zachodniopomorskie	-0.89	-0.59	8.5	9.1	6.0	70	43358	83.5	1308	13.7	8.0	0.6	14.40	2322.6	55.5	31.5

Source: author's work based on Statistic Poland – Local Data Bank (2024).

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Table 3. Indicators of the socio-economic development of Polish voivodeships in 2022

Specification	D1	D2	L1	S1	S2	S4	G1	G3	G4	I1	I2	I3	I4	F1	F2	F3
dolnośląskie	-4.62	1.24	4.5	9.0	2.5	100	90980	126.6	1 479	37.6	6.2	1.8	21.4	1163.0	57.0	49.0
kujawsko-pomorskie	-4.54	-0.91	7.3	17.7	5.2	60	66547	74.4	1094	29.9	4.6	1.5	20.3	1381.0	45.9	67.6
lubelskie	-4.78	-2.22	8.0	22.6	3.8	87	55182	62.3	1018	25.4	8.8	1.2	24.2	2050.8	40.4	72.1
lubuskie	-4.65	-0.78	4.4	13.3	3.8	29	66313	85.3	1301	20.4	3.6	0.5	19.6	3629.6	49.6	61.1
łódzkie	-6.37	-0.66	5.5	14.1	3.3	66	76228	90.4	1166	24.3	6.5	1.2	21.5	1733.9	52.7	35.8
małopolskie	-1.42	1.20	4.4	13.6	3.0	108	72004	71.1	1350	29.4	6.2	2.4	19.4	815.1	50.0	55.1
mazowieckie	-2.24	2.05	4.3	10.6	2.8	101	239236	172.7	1758	36.6	6.7	3.1	21.5	698.1	60.0	29.2
opolskie	-5.24	-1.29	5.9	12.1	3.1	59	64383	100.0	1173	30.3	4.1	0.7	20.3	2985.3	50.6	66.8
podkarpackie	-2.46	-1.00	8.8	17.4	4.4	64	55125	63.8	977	39.0	5.5	1.1	22.5	2064.2	41.2	93.1
podlaskie	-3.76	-1.00	7.0	23.4	4.6	61	59818	61.4	1023	33.1	5.2	0.9	22.7	2639.5	45.7	71.5
pomorskie	-1.89	1.66	4.6	13.7	3.6	85	81149	87.6	1461	36.3	5.8	1.7	22.4	1349.4	53.1	33.6
śląskie	-5.76	-0.97	3.7	7.8	2.4	66	85131	108.0	1201	37.5	6.2	1.1	18.9	1718.2	53.9	39.7
świętokrzyskie	-6.45	-1.89	7.8	14.8	4.6	42	56507	60.7	1077	29.2	4.7	0.5	14.3	3042.6	41.0	50.6
warmińsko-mazurskie	-4.54	-1.65	8.6	20.6	6.0	48	56368	58.9	1053	20.9	2.7	0.8	20.5	2562.5	44.8	59.5
wielkopolskie	-2.16	0.40	2.9	14.4	3.3	80	85867	107.5	1406	25.5	5.9	1.2	19.0	1652.2	51.4	34.1
zachodniopomorskie	-5.33	-0.31	6.7	13.5	3.5	49	66443	86.0	1495	29.9	4.8	0.8	15.4	2000.0	55.2	54.1

Source: author's work based on Statistic Poland – Local Data Bank (2024).

Table 4. Basic descriptive statistics for variables describing energy generation from renewable energy sources (RES) in 2017 and 2022

	2017					2022				
Variable	WO	WIL	PVA	BG	BM	WO	WIL	PVA	BG	BM
Average	3.05	18.33	0.34	0.64	3.82	3.11	26.50	66.56	0.79	3.58
standard deviation	4.00	20.88	0.39	0.27	4.83	4.07	34.14	223.55	0.35	5.26
Coefficient of variance	131.11	113.94	116.50	42.86	126.23	130.99	128.85	335.85	44.68	146.88
Skewness	1.38	2.59	2.14	0.16	2.34	1.34	2.78	3.992	0.55	2.55

Source: authors' work based on (Energy Regulatory Office, 2024) using Statistica PL.

Table 5. Polish voivodeships are divided into clusters based on energy generation from renewable energy sources (RES)

	2017	2022
Cluster 1	West Pomeranian	West Pomeranian
Cluster 2	Pomeranian, Warmian-Masurian	Podlaskie, Pomeranian, Warmian-Masurian
Cluster 3	Lublin, Podlaskie,	Świętokrzyskie
Cluster 4	Kuyavian-Pomeranian, Lubusz, Subcarpathian	Lesser Poland, Opole, Subcarpathian
Cluster 5	Lesser Poland, Opole, Świętokrzyskie	Kuyavian-Pomeranian, Lubusz
Cluster 6	Lower Silesian, Łódź, Masovian, Silesian, Greater Poland	Lower Silesian, Lublin, Łódź, Masovian, Silesian, Greater Poland

Source: authors' work based on (Energy Regulatory Office, 2024) using Statistica PL.

Cluster 6 was the largest group, consisting of 1/3 of all Polish voivodeships. Western Pomerania formed a separate cluster due to the high output of windfarms and biogas plants, and it was the leading Polish voivodeship in terms of electricity generated from wind. In 2017, Świętokrzyskie voivodeship was grouped in cluster 5 together with the voivodeships of Lesser Poland and Opole due to the low amount of electricity generated from all analysed RES. In 2022, Świętokrzyskie topped the ranking in terms of solar power output, which reached 904.392 MW per 100,000 population. In 2017, the output of photovoltaic power plants was highest in Lublin and Podlaskie, and these voivodeships were grouped in cluster 3. In 2022, Lublin voivodeship ranked eighth in terms of solar output, and it was assigned to cluster 6.

Polish voivodeships were ranked in terms of variables describing local socio-economic development and renewable energy production with the use of a linear ordering method (aggregate measure). The results were presented in descending order from the highest performing (rank 1) to the lowest performing (rank 16) voivodeship. (Table 6).

Table 6. Ranking of Polish voivodeships based on the values of RES variables and the indicators of socio-economic development in 2017 and 2022

Voivodeship	OZE		Development indicators	
	2017	2022	2017	2022
Lower Silesian	9	10	2	2
Kuyavian-Pomeranian	1	1	14	13
Lublin	6	14	12	10
Lubusz	5	4	9	12
Łódź	12	11	10	14

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Voivodeship	OZE		Development indicators	
	2017	2022	2017	2022
Lesser Poland	13	13	4	4
Masovian	14	15	1	1
Opole	15	12	8	7
Subcarpathian	8	8	11	8
Podlaskie	3	9	15	9
Pomeranian	7	6	3	3
Silesian	16	16	6	5
Świętokrzyskie	11	3	13	16
Warmian-Masurian	4	5	16	15
Greater Poland	10	7	5	6
West Pomeranian	2	2	7	11

Source: authors' work based on (Energy Regulatory Office, 2024; Statistics Poland, 2024) using Statistica PL.

The results were evaluated by calculating Spearman's rank correlation coefficients for the appropriate ranks (Table 4). Correlation coefficients were calculated between the ranks based on the values of RES variables and the indicators of socio-economic development in the corresponding years. Correlation coefficients reached -0.53 for 2017 data and -0.59 for 2022 data. It can be assumed that at the significance level of 0.05, there was no similarity in the rankings of Polish voivodeships between the analysed groups of variables in 2017 and 2022.

An analysis of the ranking results revealed that the voivodeships that scored higher in socio-economic development at the same time scored lower in renewable energy production. The voivodship of Kuyavia-Pomerania was characterised by the highest renewable energy output, but it ranked 14th in 2017 and 13th in 2022 in terms of socio-economic development. In turn, Warmian-Masurian, which occupies the last place in Poland in terms of socio-economic development, was ranked as the fourth largest producer of renewable energy in the country. Mazovian, the most economically and socially developed Polish voivodeship, ranked second last in terms of renewable energy generation in 2022. These differences are analysed in detail in the Discussion section.

Discussion

The study revealed that renewable energy production was higher in regions characterised by lower levels of socio-economic development. This observation requires an in-depth analysis and a review of the literature data. As mentioned in the Introduction, the majority of researchers have suggested that in the EU, higher levels of economic growth are accompanied by higher production of renewable energy. However, due to the specificity of Polish regions, these findings can be analysed at the local level and extrapolated to the prospects for RES development in Central-Eastern European countries with similar socio-economic conditions.

It should be emphasised that the transition to a low-carbon economy poses a considerable challenge for Poland at the macroeconomic, mesoeconomic, and microeconomic levels. Poland's economic growth is somewhat impeded by historical, geopolitical, and economic factors. The key challenge in the shift to a low-carbon economy stems from the fact that renewable energy generation requires advanced technologies (Dzikuć et al., 2021). Investments in RES are costly because they entail the construction of new power plants, as well as power grid upgrades to guarantee effective transfer of the generated electricity (Wojciechowska, 2021). For this reason, innovative solutions require considerable funding, which is why less developed regions offer less supportive conditions for these types of projects. As demonstrated by the present research and other studies examining the determinants of renewable energy growth in less developed regions, Polish voivodeships may differ from other EU regions in this respect.

The key factor that facilitates RES projects in less developed Polish regions is the availability of land and natural resources. Less urbanised areas are generally characterised by a higher percentage of vacant land that can be used for the construction of wind farms, photovoltaic power stations, and biomass plants.

It should also be noted that renewable energy installations may be arduous or dangerous for local residents, which is why they are often built in areas with less developed infrastructure and lower population density (Standar et al., 2021). Access roads and grid connections for renewable energy are also easier to build in sparsely populated areas. In many cases, these areas and types of land have remained uncultivated and unused for many years (Blanco-Canqui, 2016; Borrelli et al., 2016; Havrysh et al., 2022).

Less developed Polish regions have considerable potential for renewable energy growth. As previously noted, these regions abound in vacant land that can be utilised in the construction of clean energy installations. At the same time, due to the high levels of agricultural pollution, these areas can both benefit from and drive the development of renewables (Kistowski & Wiśniewski, 2020).

Renewable energy plays a key role in the EU's energy policy, and the EU offers structural funds to potential beneficiaries and investors in the RE sector. The EU has been providing financial support for renewable energy projects since 1997. Less developed European regions receive more structural fund assistance and, as previously mentioned, these areas could be more attractive for renewable energy projects. It should also be noted that RES projects co-financed by the EU are more often implemented in regions with lower levels of socio-economic development, entrepreneurship and agricultural activity. In some Polish regions, RES projects were negatively correlated with GDP per capita (Gradziuk & Gradziuk, 2020), which corroborates the results of the present study.

Conclusions

Poland has a massive potential for RES development, and the relationship between RES and socio-economic development suggests that much of this potential remains untapped. The above applies particularly to Polish regions with the lowest share of RES in electricity generation.

As mentioned in the Introduction, renewable energy is often regarded as an opportunity for local economic growth. Renewables can create a strong impetus for local markets by attracting new businesses, in particular companies that build, provide technical support, and manage renewable energy installations. These initiatives can also stimulate the labour market by creating new jobs in the green sector. In turn, higher employment in the green industry contributes to sustainable resource use. To promote the long-term growth of local economies, regional authorities should focus mainly on attracting high-tech companies and R&D institutes.

The results of this study and the literature data point to the specificity of renewable energy production in Polish regions. Renewable energy projects attract particular interest in rural areas and less affluent regions that have been economically and socially marginalised for many years. At present, these regions are emerging as important stakeholders in the debate on the future of the RE industry. According to many authors, less developed regions are introducing policy tools for smart specialisation strategies in green transformation, and in the future, these areas will implement the EU's energy and climate policy with the support of EU funding programs.

The contribution of the authors

Conceptualisation, A.W.; literature review, A.W., and A.S.; methodology, A.W., M.K., and A.S.; formal analysis, A.W., M.K., and A.S.; conclusions and discussion, A.W., M.K., and A.S.

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PRODUKCJA ODNAWIALNYCH ŹRÓDEŁ ENERGII A ROZWÓJ SPOŁECZNO-GOSPODARCZY REGIONÓW NA PRZYKŁADZIE POLSKI

STRESZCZENIE: W artykule podjęto problem produkcji energii z odnawialnych źródeł energii i jej oceny w kontekście rozwoju społeczno-gospodarczego regionów Polski. Wśród globalnych problemów gospodarczych, takich jak niedobór surowców i zmiany klimatyczne, OZE stają się kluczowym rozwiązaniem a także wyzwaniem patrząc na konieczność transformacji gospodarek w kierunku niskoemisyjnym. Problematyka ta wpisuje się w tematykę zrównoważonę rozwoju, obejmującą aspekty środowiskowe, społeczne i ekonomiczne w dążeniu do dbałości o potrzeby przyszłych pokoleń. Celem badań była ocena poziomu produkcji energii z OZE w województwach Polski i jej związku z poziomem rozwoju społeczno-gospodarczego. Do realizacji celu zastosowano metody aglomeracyjne i porządkowania liniowego, które umożliwiły grupowanie województw Polski pod kątem poziomu produkcji OZE, a także ich rangowanie pod kątem rozwoju społecznego gospodarczego w zestawieniu z produkajcją OZE. Dane z lat 2017 i 2022 posłużyły do oceny zmian, które zaszły w dłużej perspektywie. Wyniki badań wskazują na znaczące różnice między regionami Polski w produkcji energii z OZE oraz na negatywny związek z rozwojem społeczno-gospodarczym, co podyktowane jest specyfiką polskich regionów. Z pewnością rozwój produkcji energii z OZE jest dużym wyzwaniem stojącym przed Polską, istnieje w tym zakresie nadal wiele niewykorzstanego potencjału. Należy jednak zwrócić uwagę na korzyści, które są obserwowane na obszarach najsłabiej rozwiniętych, które w przyszłości mogą przełożyć się na wzrost dobrobytu mieszkańców całego państwa.

SŁOWA KLUCZOWE: odnawialne źródła energii; rozwój społeczno-gospodarczy; polityka regionalna

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