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THE LEVEL OF RENEWABLE ENERGY USED IN EU MEMBER STATES – A MULTIDIMENSIONAL COMPARATIVE ANALYSIS

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ABSTRACT: This paper assesses EU countries in terms of their level of renewable energy use. The ranking of 27 EU countries in terms of the complex phenomenon under study was constructed on the basis of 7 variables. The research period was 2011 and 2020. The research method was one of multidimensional comparative analysis methods, i.e. Hellwig's pattern development model. The research results confirm that there wasa positive change in the use of renewable energy in all EU countries in 2020 compared to 2011, with Sweden, Austria, Finland, and Denmark taking the lead. However, most EU countries (16 in 2011 and 17 in 2020) have a medium-low level of use of "green energy". A low level was identified in Cyprus and Malta in 2011 and Poland in 2020.

KEYWORDS: renewable energy, European Union, synthetic measure, ranking, classification

Introduction

The threat of conventional raw materials becoming depleted worldwide and the negative environmental impacts associated with raw material extraction and processing fuel the search for renewable energy sources.

Renewable energy sources (RES) represent an important contributor to slowing down the dangerous climate change on our planet. Their use in national energy balances not only serves to implement guidelines resulting from global agreements, mainly on the grounds of the UN or the EU energy and climate policy or national energy strategies but is also an economically conditioned activity (Młynarski, 2017; Tomaszewski & Seksiński, 2020). It has been found that a larger share of renewable energy is associated with lower inflation (Bednář et al., 2022) and, under favourable economic cycle circumstances, shifts the long-run Phillipse curve leftwards (Kaderabkova et al., 2020). Renewable energy constitutes a key pillar of the Industry 4.0 EU project (Hejdukova et al., 2020). Energy production from renewable sources is also becoming cheaper every year due to technological advances. Renewable energy sources have evolved from a technological novelty to a viable tool, enabling energy production to meet the growing needs of the world's population (Devine-Wright, 2019; Młynarski, 2019; Papież et al., 2018).

In the coming years, interest in the use of renewable energy sources is expected to increase due to the benefits of their application (increased energy security, creation of new jobs in the European Union, promotion of regional development), decrease in level of poverty (Łuczak & Kalinowski, 2022), cushions energy and housing poverty (Cermakova et al., 2022) and the environmental benefits, primarily the reduction of carbon dioxide emissions (Jabłoński & Wnuk, 2009). However, the current energy crisis has revealed that the transition to renewable energy is too slow and that serious efforts are needed to accelerate the transition from fossil fuels to renewable energy (Hosseini, 2022).

It is becoming essential not to treat economic development and environmental protection as separate spheres but as strongly linked tasks and to prevent economic development from leading to environmental degradation. Every human activity interferes with the environment, so it is important that this interference is related to its degradation to the least extent possible (Mickiewicz & Zuzek, 2012).

At present, the world's energy industry faces difficult tasks, including multiplying the amount of energy produced or replacing energy technologies based on burning fossil fuels with more modern ones (Mickiewicz & Zuzek, 2012).

DOI: 10.34659/eis.2023.86.3.558

The increased production of renewable energy is the response to growing concerns about energy security and energy self-sufficiency worldwide its own policy depending on its economic circumstances (Bórawski et al., 2020).

However, the widespread use of renewable energy sources requires good groundwork on the part of a given country and its central authorities, both in terms of infrastructure and legislation (Ruszel, 2016; Tomaszewski & Sekściński, 2020).

It, therefore, becomes necessary to create long-term scenarios taking into account multiple variables and the participation of a wide range of stakeholders (i.e. the presence of not only energy-producing and energy-consuming economic actors but also international organisations and specialised institutions and agencies, as well as the state as an active participant in the energy market (Niedziółka, 2012). This is why it is crucial to assess a given country in terms of its use of different renewable energy sources.

The goal of this paper is to provide a multidimensional comparative analysis of EU countries in terms of the level of renewable energy use in 2011 and 2020.

The research objective has been achieved by taking the following steps:

- conducting a literature review on renewable energy and its significance,
- collecting statistical data on the level of renewable energy use for the period 2011–2020 for the EU countries and carrying out statistical verification,
- determining the value of the synthetic measure using Hellwig's development pattern model and building the rankings of EU countries in 2011 and 2020,
- classifying EU countries into groups with a similar level of achievement of the studied phenomenon.

The paper is organised as follows. First, we present the importance and types of renewable energy used in the economy. The following part describes the research methodology. The third section describes the study results. Next, the final part presents the discussion and our conclusions.

Renewable energy sources – literature review

The increase in the share of renewable energy sources in the world's fuel and energy balance contributes to improving the efficiency of the use and saving of energy resources and the environment by reducing pollutants to the atmosphere, water and the amount of waste produced (Mickiewicz & Zuzek, 2012).

Renewable energy sources are replenished by natural processes, thus being inexhaustible. They include the following: directly used solar energy,

DOI: 10.34659/eis.2023.86.3.558

kinetic energy of winds, energy from the Earth's crust (geothermal energy), river energy, marine energy, energy from the interior of the oceans, part of municipal and industrial waste that is suitable for energy processing (e.g. organic waste and sewage).

Renewable energy is the amount of energy obtained through constantly renewable natural processes. Having various forms, it is generated directly or indirectly by solar energy or from heat from the Earth's core.

Most of the world's energy is produced using primary fuels such as coal, lignite, oil, natural gas and uranium. At present, these raw materials are not in short supply, but their sources are not eternal, and soon, due to the increasing demand for energy, mankind will be forced to switch completely to alternative energy sources (Mickiewicz & Zuzek, 2012). In some areas of the world, renewable energy can solve the lack of energy, making it possible to reduce greenhouse gas emissions as well. However, the application of renewable technologies depends heavily on national conditions (Angheluta et al., 2019), uncertainty related to global warming, the spread of COVID-19 and the Russian-Ukrainian war (Bednář et al., 2022). Each country must determine its own policy depending on its economic circumstances (Bórawski et al., 2020).

The paper presents the advantages and disadvantages of using selected renewable energy sources. They include the following (Mickiewicz & Zuzek, 2012):

- Solar energy. Among the non-conventional sources, it has the least negative impact on the environment, has unlimited resources, is ubiquitous and may be directly converted (via photovoltaic, chemical or photochemical conversion) to other forms of energy. The disadvantages of solar energy include its cyclic nature (both diurnal and annual disproportions), its considerable seasonal dispersion, the dependence of solar radiation on the angle of incidence of the sun's rays, its dependence on atmospheric conditions and the high cost of the equipment enabling its conversion. However, it should be noted (Górzyński, 2017) that the cost of manufacturing and installing photovoltaic modules is on a downward trend. Developments in technology, the decreasing cost of photovoltaic module components and readily available solar energy resources are leading to increasingly affordable solutions and applications.
- Earth energy. It is one type of renewable energy source stored in soils, rocks and fluids filling pores and rock fissures. It involves using the thermal energy of the Earth's interior, particularly in areas of volcanic and seismic activity. The use of geothermal energy to generate thermal energy is more cost-effective than its conversion to electricity. At present (Zou et al., 2022), it is mainly used to generate hot steam to drive turbines for power generation. Thermal energy resources are limited to areas of tec-

DOI: 10.34659/eis.2023.86.3.558

tonic activity and represent only a small fraction of the total potential available geothermal energy. The cost of generating it is half that of generating it from coal. However, the use of geothermal energy can have a detrimental effect on the environment due to the possible emission of harmful gases (hydrogen sulphide, radon and carbon dioxide).

- Water energy. It uses the mechanical energy of flowing water, which can be converted into electricity (hydropower) or used directly to drive machinery (turbines or the water wheel). The mechanical energy of water can be divided into river flow energy (kinetic and potential energy are converted into electrical energy) and the mechanical energy of the oceans (water mass movements caused by tides, waves or differences in density). Hydroelectricity, despite its small share of overall production, has tangible environmental benefits. It saves thousands of tonnes of coal and ensures that the environment is free of many harmful substances (sulphur dioxide, nitrogen oxide, carbon dioxide). It also has the advantage of lower operating costs than conventional power plants and lower electricity generation costs. Unfortunately, such power plants also have their disadvantages, which include environmental interference, siltation of the river bed, changes in water levels causing landslides and bank abrasion, accumulation, sedimentation of suspended solids and noise nuisance (Malecki et al., 2015).
- Wind Energy. Wind plays a very important role in the renewable energy potential and is one of the most promising sources of alternative energy. It can be achieved with installations on land and offshore. The European Union has great potential in the production of offshore wind energy. Each year, the number of offshore wind farms has increased (Myhr et al., 2014). Future investments in wind farms require financial support that will bring additional future benefits. The technology of wind production is developing within the world and fewer losses of energy and turbine failures have been observed (Bórawski et al., 2020).
- Biomass energy. Biomass usually takes the form of wood, hay, straw, sewage sludge or municipal waste. The use of biomass is beneficial from an environmental point of view, not only due to reduced emissions. By obtaining energy from biomass, we prevent food surpluses from going to waste, we manage production waste from the forestry and agricultural industries, and we dispose of municipal waste. An additional benefit is that the odour of decomposing waste in the landfill becomes less intensive and the environmental condition in the vicinity of the landfill is significantly improved. Disadvantages include the following: the relatively low density of the raw material, which makes it difficult to transport, store and dispense; the wide moisture range of biomass, which makes it difficult to prepare for energy use; the lower energy value of the raw

DOI: 10.34659/eis.2023.86.3.558

material compared to fossil fuels (for example, about 2 tonnes of wood or straw are needed to produce the same amount of energy as from a tonne of good quality coal); and the fact that some waste is only available seasonally.

The use of biomass for bioenergy production must take into account the use of all available resources in a sustainable manner without negative impacts. Therefore, only the technical potential of agricultural biomass should be used for energy purposes (Scarlat et al., 2010).

An increase in the share of renewable energy in total energy consumption is one of the priorities of the European Union in the climate and energy policy (Kozłowski, 2022). Research shows that the share of energy from renewable sources in EU countries is growing every year. Over the last 15 years, the share of energy from renewable sources has more than doubled and has amounted to 22.1% in 2020 (10.2% in 2005) (Janiszewska & Ossowska, 2022).

Research methods

A selected method of multidimensional comparative analysis (MCA) was used to build a ranking of EU countries in terms of the level of renewable energy use in 2011 and in 2020.

The essence of multidimensional comparative analysis is the determination of a synthetic (aggregate) measure, which is a function of multiple variables. This makes it possible to order objects in multidimensional spaces of diagnostic variables. Information on MCA methods can be found, inter alia, in works by (Balicki, 2009; Fura, 2015; Giri, 2004; Grabiński et al., 1989; Kukuła, 2000; Malinowski & Jaworska, 2018; Młodak, 2006; Nowak, 1990; Panek, 2009; Stec, 2013; Stec, 2021; Stec et al., 2014; Strahl, 2006; Walesiak & Gatnar, 2009; Wysocki, 2010; Zeliaś, 2000).

From among the numerous MAC methods, Hellwig's development pattern model has been selected for this study. It was developed in 1968 by Zdzisław Hellwig and was the first proposal of a synthetic measure in the Polish taxonomic literature, significantly developing this field of knowledge.

The basic assumptions of the Hellwig's method are as follows (Hellwig, 1968):

The values of the variables X_j (j = 1, 2, ..., m) corresponding to individual objects O_i (i = 1, 2, ..., n) are presented in the form of a matrix of observations:

$$\boldsymbol{X} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nm} \end{bmatrix}, \tag{1}$$

1. The values of the variables X_j are standardised in the studied set of objects according to the following formula:

$$z_{ij} = \frac{x_{ij} - \bar{x}_j}{S_j}, \tag{2}$$

where:
z_{ij} – the normalised value of a *j*-th variable for the *i*-th object,
x_{ij} – the value of a *j*-th variable for the *i*-th object,
$\bar{x}_j$ – mean of a *j*-th variable,
S_j - standard deviation of a *j*-th variable.

2. The coordinates of the development pattern are established using the following relation:

$$\begin{cases} z_{0j} = \max_i z_{ij}\ , & \text{for stimulants} \\ z_{0j} = \min_i z_{ij}\ , & \text{for destimulants} \end{cases}, \tag{3}$$

3. The following formula is used:

$$D_{io} = \sqrt{\sum_{j=1}^{m} \left(z_{ij} - z_{oj}\right)^2}\ , \tag{4}$$

to calculate Euclidean distances of objects from the pattern, obtaining a sequence of distance values $D_{10}, D_{20},...,D_{n0},$

$$\overline{D}_o = \frac{1}{n}\sum_{i=1}^{n} D_{io}, \tag{5}$$

and the standard deviation of these distances:

$$S_o = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(D_{io} - \bar{D}_o)^2}, \tag{6}$$

4. The value is then determined as:

$$D_0 = \overline{D}_0 + 2S_0, \tag{7}$$

5 The measure of development has the following form:

$$MS_i = 1 - \frac{D_{io}}{D_o}, \tag{8}$$

The higher the value of the measure of , the more developed the object in terms of the complex phenomenon.

The calculated values of the synthetic measures of the complex phenomenon (the level of renewable energy use in the EU countries) in 2011 and in 2020 can provide a basis for an overall assessment of their changes and the level of differentiation. In his studies, Walesiak (1993; 2011; Fura et al., 2020) presents a measure with the following form:

$$P^2(MS_r, MS_s) = P_{rs}^2 = \frac{1}{n}\sum_{i=1}^{n}(p_{ir} - p_{is})^2, \tag{9}$$

where:
p_{ir},p_{is} – values of synthetic measure for the *i*th country in the compared periods *r* and *s*,
n – number of countries.

The measure helps to compare the values of the general synthetic measure at the beginning and end of the studied period. Its value is 0 when there are no differences in the values of synthetic measures in the compared periods. The square root of formula (9) informs about the average order of deviation in the compared synthetic values in periods *r* (2011) and *s* (2021).

An important feature of P_{rs}^2 measure is that it can be presented as a sum of three partial measures, which enables more precise identification of the "order" and "nature" of the differences in the synthetic measure values, in the following form:

$$P_{rs}^2 = P_1^2 + P_2^2 + P_3^2, \tag{10}$$

Individual partial measures provide information about the following:

- a difference between mean values ofsynthetic measures:

$$P_1^2 = (\overline{p}_{.r} - \overline{p}_{.s})^2 , \quad (11)$$

- a difference in the dispersion of synthetic measures:

$$P_2^2 = (S_r - S_s)^2 , \quad (12)$$

- a non-conformity of the direction of changes in synthetic measures:

$$P_3^2 = 2S_r S_s (1 - \rho) , \quad (13)$$

where:
$\overline{p}_{.r}$, S_r ($\overline{p}_{.s}$, S_s) stand for the following, respectively arithmetic mean and standard deviation of the *r*th (*s*th) synthetic feature value,
ρ – Pearson's coefficient of linear correlation between vectors $p_{.r}=(p_{1r},...p_{nr})$ and $p_{.s}=(p_{1s},...p_{ns})$.

EU countries can be divided into groups similar in terms of renewable energy use with the following scheme (Nowak, 1990):

$$\begin{array}{lll} \text{Group 1: } MS_i \geq \overline{MS}_i + S_i & \text{high level} & \\ \text{Group 2: } \overline{MS}_i + S_i > MS_i \geq \overline{MS}_i & \text{medium-high level} & \\ \text{Group 3: } \overline{MS}_i > MS_i \geq \overline{MS}_i - S_i & \text{medium-low level} & \\ \text{Group 4: } MS_i < \overline{MS}_i - S_i & \text{low level} & \end{array} \quad (14)$$

where:
$\overline{MS}_i$ – the mean value of the synthetic measure,
S_i – standard deviation of the synthetic measure.

Results of the research and discusion

The level of renewable energy use in the EU countries in 2011 and 2020 was assessed on the basis of a set of the following variables:

- X1 – Share of energy from renewable sources (% of gross final energy consumption),
- X2 – Energy production from renewable sources (wind energy in megawatt per 100.000 population),

- X3 – Energy production from renewable sources (hydro energy in megawatt per 100.000 population),
- X4 – Energy production from renewable sources (solar energy in megawatt per 100.000 population),
- X5 – Energy production from renewable sources (solid biofuels energy in megawatt per 100.000 population),
- X6 – Share of energy from renewable sources for heating and cooling (% of gross final energy consumption),
- X7 – Share of energy from renewable sources in transport (% of gross final energy consumption).

All variables are stimulants, i.e. high values are desirable from the point of view of the phenomenon under study, while low values are undesirable.

The values of the variables in 2011 and 2020 are presented in Tables 1 and 2, taken from the Eurostat database, some of them converted per 100,000 population.

Table 1. Values of variables determining the level of renewable energy use in EU countries in 2011

Countries	X1	X2	X3	X4	X5	X6	X7
Belgium	6.30	9.72	12.96	17.99	6.37	6.72	4.80
Bulgaria	14.15	7.34	42.17	2.09	0.08	24.77	0.90
Czechia	10.95	2.03	20.95	18.24	2.92	15.39	1.29
Denmark	23.39	71.07	0.17	0.31	16.56	31.89	3.61
Germany	12.47	35.79	14.26	32.31	1.94	12.61	6.46
Estonia	25.52	13.54	0.38	0.00	10.91	44.55	0.45
Ireland	6.61	34.67	5.18	0.02	0.12	4.66	3.84
Greece	11.15	14.74	28.98	5.50	0.00	20.11	0.60
Spain	13.18	46.13	39.73	11.64	1.20	13.47	0.77
France	10.81	10.40	39.46	4.62	0.51	15.26	0.99
Croatia	25.39	3.03	49.63	0.00	0.14	33.82	1.03
Italy	12.88	11.65	36.62	22.12	0.71	13.82	5.06
Cyprus	6.25	15.98	0.00	1.19	0.00	19.98	0.00
Latvia	33.48	1.74	75.97	0.00	0.24	44.71	4.09
Lithuania	19.94	6.62	28.7	0.00	0.59	32.79	3.83
Luxembourg	2.86	8.70	221.61	7.95	0.00	4.74	2.36
Hungary	13.97	3.31	0.55	0.04	4.37	20.04	6.17
Malta	1.85	0.00	0.00	1.28	0.00	12.03	2.02

DOI: 10.34659/eis.2023.86.3.558

Countries	X1	X2	X3	X4	X5	X6	X7
Netherlands	4.52	13.91	0.22	0.89	0.8	3.69	5.07
Austria	31.55	13.21	157.34	2.08	19.44	31.52	10.08
Poland	10.34	4.73	6.16	0.00	0.46	13.24	6.92
Portugal	24.6	40.26	52.35	1.63	4.52	35.18	0.69
Romania	21.74	4.89	32.10	0.00	0.13	24.31	5.53
Slovenia	20.94	0.00	61.12	2.78	1.61	31.79	2.48
Slovakia	10.35	0.06	46.79	9.20	3.17	9.26	5.73
Finland	32.53	3.70	57.3	0.13	32.72	45.73	1.00
Sweden	47.63	29.36	176.06	0.13	36.08	58.52	11.94

Source: authors' work based on Eurostat [20-11-2022].

Table 2. Values of variables determining the level of renewable energy use in EU countries in 2020

Countries	X1	X2	X3	X4	X5	X6	X7
Belgium	13.00	40.62	12.29	48.38	4.89	8.45	11.03
Bulgaria	23.32	10.11	48.57	15.79	0.22	37.18	9.10
Czechia	17.30	3.17	21.18	19.85	4.23	23.53	9.38
Denmark	31.68	107.50	0.12	22.40	25.50	51.07	9.57
Germany	19.31	74.78	12.98	64.59	1.92	14.81	9.92
Estonia	30.07	23.85	0.60	15.63	15.05	57.90	12.16
Ireland	16.16	86.75	10.66	1.87	0.14	6.26	10.19
Greece	21.75	38.43	31.88	30.67	0.13	31.94	5.34
Spain	21.22	56.66	42.50	26.60	1.83	17.97	9.53
France	19.11	25.91	38.10	17.81	1.25	23.37	9.21
Croatia	31.02	19.75	54.20	2.67	1.98	36.93	6.59
Italy	20.36	18.23	38.05	36.30	1.22	19.95	10.74
Cyprus	16.88	17.76	0.00	25.80	0.00	37.12	7.40
Latvia	42.13	4.08	83.15	0.27	5.04	57.09	6.73
Lithuania	26.77	19.33	31.39	5.87	2.25	50.35	5.50
Luxembourg	11.70	24.40	212.51	29.81	5.61	12.61	12.58
Hungary	13.85	3.29	0.59	21.81	4.06	17.72	11.57
Malta	10.71	0.02	0.00	36.51	0.00	23.03	10.59

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Countries	X1	X2	X3	X4	X5	X6	X7
Netherlands	14.00	38.02	0.21	62.90	1.55	8.05	12.63
Austria	36.55	36.24	164.08	22.95	9.17	34.99	10.28
Poland	16.10	16.59	6.32	10.42	1.93	22.14	6.58
Portugal	33.98	49.75	70.33	10.69	5.86	41.55	9.70
Romania	24.48	15.59	34.42	7.15	0.70	25.33	8.54
Slovenia	25.00	0.16	64.50	17.64	1.67	32.14	10.91
Slovakia	17.35	0.07	46.34	9.80	2.51	19.43	9.26
Finland	43.80	46.80	57.26	5.76	44.20	57.62	13.44
Sweden	60.12	96.60	158.86	10.72	28.49	66.38	31.85

Source: authors' work based on Eurostat [20-11-2022].

A prerequisite for the correct application of the proposed MCA method is to check the initial set of variables determining the level of renewable energy use (variables X1-X7) in the EU countries in terms of variability and correlation, i.e. selection of diagnostic variables. The basic statistical measures for the variables for 2011 and 2020 are provided in Table 3.

Table 3. Descriptive statistics of variables in 2011 and 2020

Indicator	X1	X2	X3	X4	X5	X6	X7
2011							
Mean	16.86	15.06	44.69	5.26	5.39	23.13	3.62
Coefficient of variation (CV)	0.64	1.12	1.22	1.55	1.77	0.61	0.82
Coefficient ofasymmetry (CA)	0.94	1.79	2.04	1.97	2.32	0.66	1.04
Maximum value	47.63	71.07	221.61	32.31	36.08	58.52	11.94
Minimum value	1.85	0.00	0.00	0.00	0.00	3.69	0.00
2020							
Mean	24.36	32.39	45.97	21.51	6.35	30.92	10.38
Coefficient of variation (CV)	0.46	0.91	1.15	0.77	1.61	0.54	0.45
Coefficient ofasymmetry (CA)	1.41	1.15	1.85	1.19	2.59	0.51	3.59
Maximum value	60.12	107.50	212.51	64.59	44.20	66.38	31.85
Minimum value	10.71	0.02	0.00	0.27	0.00	6.26	5.34

Source: authors' work based on Eurostat [20-11-2022].

DOI: 10.34659/eis.2023.86.3.558

The coefficient of variation, calculated as the ratio of the standard deviation of a variable to its arithmetic mean in both years under study, was at the desired level (above 0.10) for all variables. In 2011, the lowest value (0.61) was obtained for the variable X6- Share of energy from renewable sources for heating and cooling (% of gross final energy consumption), while the highest value (1.77) was obtained for the variable X5- Energy production from renewable sources (solid biofuels energy in megawatt per 100,000 population).

In 2011, the highest values for as many as four variables (X1, X3, X6, X7) were recorded by Sweden. As for the other variables, the leaders were: Denmark (X2), Luxembourg (X3) and Germany (X4). EU countries were also characterised by high right-handed asymmetry, especially in terms of variables X3, X5. This means that the majority of countries had values of the examined variables below the average level.

In 2020, EU countries were also highly heterogeneous in terms of variables (X1-X7). The coefficient of variation ranged from 0.45 for variable X7 – Share of energy from renewable sources in transport (% of gross final energy consumption) to 1.61 for X5- Energy production from renewable sources (solid biofuels energy in megawatt per 100,000 population). Compared to 2011, there was no change in the leaders of renewable energy use in 2020. Only in terms of the value of variable X5, Finland replaced Sweden.

The correlation between variables X1–X7 was also assessed by determining Pearson's linear correlation coefficient values (Table 4).

Table 4. Correlation matrix between variables in 2020

Variable	X1	X2	X3	X4	X5	X6	X7
X1	1.0000	0.3784	0.4530	-0.4714	0.6921	0.8518	0.5198
X2	0.3784	1.0000	0.0816	0.1319	0.4782	0.1487	0.4397
X3	0.4530	0.0816	1.0000	-0.1984	0.2408	0.2210	0.4328
X4	-0.4714	0.1319	-0.1984	1.0000	-0.2244	-0.5277	0.0440
X5	0.6921	0.4782	0.2408	-0.2244	1.0000	0.6375	0.5515
X6	0.8518	0.1487	0.2210	-0.5277	0.6375	1.0000	0.2794
X7	0.5198	0.4397	0.4328	0.0440	0.5515	0.2794	1.0000

The inverse correlation matrix method of Malina and Zeliaś was then applied (Malina & Zeliaś, 1997; Malina & Zeliaś, 1998). When a variable is excessively correlated with the other variables, the diagonal elements of the inverse correlation matrix ($\boldsymbol{R}^{-1}$) are significantly greater than unity. A variable is considered overly correlated when these elements exceed a value of 10.

Table 5. Values of the synthetic measure and ranking of EU countries for the level of renewable energy use in 2011 and in 2020

Country	2011	2020		Country	2011		Country	2020
Belgium	0.1357	0.2624	1	Sweden	0.4647	1	Sweden	0.6758
Bulgaria	0.1177	0.2503	2	Austria	0.3466	2	Finland	0.4648
Czechia	0.1201	0.2185	3	Finland	0.2495	3	Denmark	0.4140
Denmark	0.2452	0.4140	4	Denmark	0.2452	4	Austria	0.4100
Germany	0.2081	0.3030	5	Germany	0.2081	5	Portugal	0.3482
Estonia	0.1708	0.3395	6	Latvia	0.2072	6	Estonia	0.3395
Ireland	0.0958	0.2045	7	Portugal	0.2022	7	Luxembourg	0.3126
Greece	0.1097	0.2557	8	Estonia	0.1708	8	Germany	0.3030
Spain	0.1544	0.2899	9	Italy	0.1706	9	Spain	0.2899
France	0.1057	0.2446	10	Slovenia	0.1606	10	Latvia	0.2716
Croatia	0.1477	0.2419	11	Romania	0.1600	11	Italy	0.2699
Italy	0.1706	0.2699	12	Lithuania	0.1544	12	Slovenia	0.2645
Cyprus	0.0701	0.2180	13	Spain	0.1544	13	Belgium	0.2624
Latvia	0.2072	0.2716	14	Croatia	0.1477	14	Netherlands	0.2575
Lithuania	0.1544	0.2304	15	Slovakia	0.1399	15	Greece	0.2557
Luxembourg	0.1212	0.3126	16	Hungary	0.1358	16	Bulgaria	0.2503
Hungary	0.1358	0.2053	17	Belgium	0.1357	17	France	0.2446
Malta	0.0461	0.1970	18	Luxembourg	0.1212	18	Croatia	0.2419
Netherlands	0.0794	0.2575	19	Czechia	0.1201	19	Lithuania	0.2304
Austria	0.3466	0.4100	20	Bulgaria	0.1177	20	Romania	0.2200
Poland	0.1142	0.1776	21	Poland	0.1142	21	Czechia	0.2185
Portugal	0.2022	0.3482	22	Greece	0.1097	22	Cyprus	0.2180
Romania	0.1600	0.2200	23	France	0.1057	23	Hungary	0.2053
Slovenia	0.1606	0.2645	24	Ireland	0.0958	24	Ireland	0.2045
Slovakia	0.1399	0.1980	25	Netherlands	0.0794	25	Slovakia	0.1980
Finland	0.2495	0.4648	26	Cyprus	0.0701	26	Malta	0.1970
Sweden	0.4647	0.6758	27	Malta	0.0461	27	Poland	0.1776

DOI: 10.34659/eis.2023.86.3.558

In the study, the diagonal elements of the inverse correlation matrix for the variables X1-X7 in 2020 met the required criterion and ranged from 1.64 to 8.14. Thus, all initially proposed variables became diagnostic variables in both 2011 and 2020.

In the next stage of the research, based on the values of the diagnostic variables determining the level of renewable energy use in 2011 and in 2020, the Hellwig's development pattern method was used to determine the values of the synthetic measure and a ranking of EU countries was constructed (Table 5).

When comparing the values of the synthetic measure in 2020 and in 2011 for the EU countries, it can be seen that there was an increase in the value of the indicator in all countries under study, indicating some progress in the use of renewable energy.

Among the EU countries, the following countries moved up in the ranking in the most prominent way in the years under study: Luxembourg (from the 18th place in 2011 to the 7th in 2020), Netherlands (from the 25th to 14th) and Greece (from the 22nd to 15th). By contrast, the following countries fell the most in 2020 compared to 2011: On the other hand, Slovakia (down by 10 places), Romania (down by 9), and Hungary and Lithuania (down by 7). Poland's situation with regard to the use of renewable energy is also worrying, as it ranked 21st in the EU countries' ranking in 2011 and 27th in 2020 (Table 5).

Using formulas no. 9 -13, the changes in the level of renewable energy use and differentiation of EU countries in 2011 and 2020 were assessed. The following results were obtained:

$$P_{rs}^2 = 0.0172,$$

$$P_1^2 = 0.0150,$$

$$P_2^2 = 0.0003,$$

$$P_3^2 = 0.0018,$$

where:
$\bar{p}_{.r} = 0.1642,$
$\bar{p}_{.s} = 0.2869, S_r = 0.0850,$
$S_s = 0.1034,$
$\rho = 0.8965.$

The measure values obtained confirm some changes in the values of the overall synthetic measure over the years studied. There was an increase in the average level and variation of the synthetic measure values. It was also observed that the direction of change of the synthetic measure values in 2011 and 2020 was highly consistent.

It is also interesting to determine which EU countries are leaders in the use of renewable energy and which use is at an average or even low level. A classification of the countries into four groups using Figure no. 14 is presented in Table 6.

Table 6. Classification of EU countries in terms of the use of renewable energy in 2011 and 2020

Group	2011	2020
Group 1: high level	Sweden, Austria, Finland	Sweden, Finland, Denmark, Austria
Group 2: medium-high level	Denmark, Germany, Latvia, Portugal, Estonia, Italy	Portugal, Estonia, Luxembourg, Germany, Spain
Group 3: medium-lowlevel	Slovenia, Romania, Lithuania, Spain, Croatia, Slovakia, Hungary, Belgium, Luxembourg, Czechia, Bulgaria, Poland, Greece, France, Ireland, Netherlands	Latvia, Italy, Slovenia, Belgium, Netherlands, Greece, Bulgaria, France, Croatia, Lithuania, Romania, Czechia, Cyprus, Hungary, Ireland, Slovakia, Malta
Group 4: lowlevel	Cyprus, Malta	Poland

In 2011, the leaders in the use of renewable energy in the EU were Sweden, Austria and Finland, with Denmark joining the group in 2020. In 2011, 6 countries (Denmark, Germany, Latvia, Portugal, Estonia, Italy) and in 2020 5 countries (Portugal, Estonia, Luxembourg, Germany, Spain) had a medium-high level of renewable energy use. In both years under study, the largest number of EU countries were classified as having medium-low levels of renewable energy use (in 2011 – 16 countries, and in 2020 – 17 countries). Low levels were recorded in Cyprus and Malta in 2011, and in 2020 – Poland (Table 6).

Conclusions

The increased share of renewable energy sources in the fuel and energy balances in individual European countries contributes to saving energy resources from primary sources (coal, oil, natural gas), improving the efficiency of their use, improving the state of the environment as a result of reduced emissions to the atmosphere and water, reducing the amount of waste and more (Jablonski & Wnuk, 2009). As a consequence, renewable energy for the European Union has long been an important aspect of the functioning of the Community (Janiszewska & Ossowska, 2018; Janiszewska & Ossowska, 2022).

DOI: 10.34659/eis.2023.86.3.558

As the importance of renewable energy sources is growing, the trend of developing the renewable energy systems sector should be maintained, providing support and solutions to ensure the implementation of new technologies and the cost-effectiveness of "clean energy" production (Stec & Grzebyk, 2022; Sowa, 2018).

An analysis of the level of use of renewable energy in EU countries in 2011 and 2020 on the basis of the value of the synthetic indicator including 7 diagnostic variables confirmed significant disparities between countries. The use of the Hellwig's pattern development model is an effective way of comparing the scale of change in the level of the phenomenon under study in the years covered by the analysis.

The research confirms that there wasa positive change in the use of renewable energy in all EU countries in 2020 compared to 2011, with Sweden, Austria, Finland, and Denmark taking the lead. However, most EU countries (16 in 2011 and 17 in 2020) have a medium-low level of use of "green energy". In contrast, while Cyprus and Malta recorded low levels in 2011, they improved their position in 2020. Unfortunately, in Poland, the level of use of renewable energy diverges significantly from other EU countries, resulting in a change in the country's position in the overall ranking, from a medium-low level in 2011 to a low level in 2020.

This shows a widening gap between the last ranked countries and the best developed ones. This is an unfavourable development in the context of the policy of levelling out regional development differences in the European Union.

Attention should be paid here also to the importance of the natural conditions in individual countries that can be used in the generation of renewable energy (having a lot of rivers, favourable wind conditions, significantly more sunny days per year, having biofuels, etc.). Also of great importance are the outlays and costs associated with obtaining and using renewable energy, which can be a heavy burden for countries with a lower level of economic development (Stec & Grzebyk, 2022). In this context, building public awareness of the importance of RES for the economy and supporting initiatives at local and regional levels (for example, through energy clusters) are also key factors.

The results can help guide appropriate regional policies, which should lead to an increase in the use of the country's resources. The effort undertaken by individual EU countries is thus resulting in an increase in the share of renewable energy in the total national energy balance. The measures taken should significantly impact reducing the use of energy from traditional raw material sources that cause environmental pollution by dust and greenhouse gases.

DOI: 10.34659/eis.2023.86.3.558

It is currently assumed that supporting the exploitation of a country's unique potential can contribute to building its competitive advantage within the European Union. In addition, the results obtained can also be applied when creating joint development strategies using the strengths of each country to best contribute to the growth of renewable energy sources in the EU as a whole.

Acknowledgements

This research was funded by the Institute of Economics and Finance, University of Rzeszów, Poland.

The contribution of the authors

Conceptualization, M.G. and M.S.; methodology, M.S.; analysis, M.G. and M.S.; writing original draft preparation, M.G. and M.S.; writing, M.G. and M.S.; visualisation, M.G. and M.S.; supervision, M.G. and M.S.; funding acquisition, M.G. and M.S.

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

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