Using MCDM Methods to Assess the Extent to which the European Union Countries Use Renewable Energy

doi:10.2478/mape-2021-0017
Date of submission to the Editor: 05/2021
Date of acceptance by the Editor: 06/2021
MAPE 2021, volume 4, issue 1, pp. 190-199

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INTRODUCTION

Energy security is one of the basic tasks carried out by individual countries. It is of great socio-economic and political significance and constitutes the basis for independent development of both economies and groups of countries. Access to adequate resources of affordable and environmentally neutral energy is the basis for sustainable energy development (Bishoge et al., 2019; Tutak et al., 2020; Tutak et al., 2021). Sustainable and modern energy is now considered to be energy produced from RES. The production and use of RES-based energy are one of the basic elements of sustainable development of the European Community (Brodny and Tutak 2020; Brodny et al., 2020b; Piwowar and Dzikuć, 2019). Such energy contributes to climate protection and has a positive impact on air quality. In addition, RES are an opportunity to ensure the energy security of individual countries and/or their groups by making them independent of fossil fuel markets (e.g., oil, natural gas) (Sorin and Anca, 2020).

Since the 1990s, in the EU energy policy, both the importance and role of RES in the structure of the energy sector have been systematically increasing.

Some of the first EU regulations in the field of RES date back to 1997, when the European Commission adopted the so-called White Paper *Energy for the Future: Renewable Energy Sources* (Kosiorek and Jarzynka, 2017). The document assumed that by 2010 the share of energy from RES would have reached 12% of total energy consumption in the EU member states. The first legal document concerning RES was Directive 2001/77/EC (Directive 2001/77/EC of the European Parliament and of the Council), which was adopted by the EU in 2001. It imposed on each member state the obligation to take appropriate measures to achieve a specific indicative target for the consumption of electricity generated from RES. At that time, a target of 12% RES-E with a 22% indicative share of electricity produced from RES by 2010 was set. Another measure was Directive 2003/30/EC (Directive 2003/30/EC of the European Parliament and of the Council) to promote the use of biofuels and other renewable fuels in transport (5.75% share of biofuels in the consumption of

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transport fuels). According to Directive 2009/28/EC, the EU countries were to increase the share of energy obtained from RES in their overall energy consumption. The European Climate and Energy Package included targets to be achieved by 2020. These involved not only increasing the share of energy consumption generated from RES to 20%, but also a 20% reduction in emissions. Additionally, it was assumed that by the end of 2020, at least 10% of final energy consumption in transport should come from RES.

In turn, in December 2019, the European Council approved the EU's climate neutrality target by 2050 in the form of a European climate strategy called the European Green Deal (European Commission: A European Green Deal). The introduction of regulations on RES has caused the EU member states to make efforts to accomplish the targets set out in the adopted Directives. The result is a steadily growing production and use of renewable energy in recent years. However, the EU countries are characterized by significant differences in the use of RES both in total and in individual sectors.

Therefore, it is reasonable to conduct research that will allow assessing the state of renewable energy in the EU countries. It is essential to determine changes that occurred in the development of renewable energy over a long period of time. In this paper, such an analysis was made for a period of 15 years (2004-2019). The aim of this research was to assess the level of RES development in the EU countries in 2004 and 2019. A set of four indicators characterizing the use of renewable energy in the EU countries and the WASPAS method (from the group of MCDM methods) were used for analysis.

METHODOLOGY OF RESEARCH

In order to evaluate the progress of RES use in the EU-27 countries for 2004 and 2019, data from the Eurostat database (Eurostat) were used.

A comparative analysis was performed using 4 indicators that characterized the studied countries in terms of renewable energy use: overall Renewable share (with aviation cap), Renewable energy in Transport, Renewable Electricity Generation, Renewable Heating and Cooling. The values of these indicators are presented in Table 1.

The Weighted Aggregated Sum Product Assessment method was used to assess the development of renewable energy use in the EU-27 countries for 2004 and 2019. The Weighted Sum Model (WSM) is one of the multi-criteria decision-making methods to evaluate multiple alternatives in terms of several decision criteria. The general assumption of this method is that a given MCDM problem is based on *m* alternatives and *n* decision criteria. Each criterion has a specific weight *wj*, and *xij* is the weighted value of variant *i* when it is evaluated against criterion *j* (Brauers and Zavadskas, 2012; Zavadskas et al., 2012).

The total relative importance of alternative *i*, denoted as $Q_i^{(1)}$, is defined as follows:

$$Q_i^{(1)} = \sum_{j=1}^{n} \overline{x_{ij}} w_j \quad (1)$$

where linear normalization of the initial values of the criteria is used, i.e.: for stimulants:

$$\overline{x_{ij}} = \frac{x_{ij}}{max x_{ij}} \quad (2)$$

or for destimulants:

$$\overline{x_{ij}} = \frac{min x_{ij}}{x_{ij}} \quad (3)$$

Table 1 Indicators for renewable energy use in EU-27 for 2004 and 2019

	2004				2019			
	RES share	RES - Transport	RES - Electricity Generation	RES - Heating and Cooling	RES share	RES in Transport	RES - Electricity Generation	RES - Heating and Cooling
	%							
Belgium	4.7	2.2	6.2	5.9	1.89	0.58	1.69	2.84
Bulgaria	12.0	1.1	10.9	21.6	9.23	0.97	8.36	14.06
Czechia	10.0	4.3	6.4	14.3	6.77	1.20	3.69	9.92
Denmark	19.9	0.7	28.3	29.5	14.84	0.45	23.75	20.62
Germany	10.9	5.9	17.5	11.2	6.21	2.14	9.44	7.20
Estonia	22.9	0.4	6.0	41.8	18.39	0.20	0.55	33.28
Ireland	5.2	2.0	14.1	4.2	2.38	0.04	6.03	2.87
Greece	8.7	1.1	11.0	17.2	7.16	0.09	7.84	13.47
Spain	13.0	3.7	27.8	13.3	8.34	1.03	18.97	9.56
France	12.2	6.6	15.1	15.0	9.51	1.55	13.78	12.54
Croatia	23.6	1.3	35.9	31.3	23.40	1.00	35.03	29.41
Italy	12.8	4.0	18.8	16.4	6.32	1.21	16.09	5.71
Cyprus	5.9	2.0	0.6	17.3	3.07	0.00	0.02	9.26
Latvia	34.3	1.9	41.9	47.9	32.79	2.14	45.96	42.49
Lithuania	19.8	4.5	5.9	33.7	17.22	0.45	3.59	30.45
Luxembourg	2.9	2.2	4.1	4.6	0.90	0.14	2.77	1.82
Hungary	11.7	5.9	7.0	17.0	4.36	1.02	2.22	6.45
Malta	0.2	0.0	0.0	2.0	0.10	0.00	0.00	1.04
Netherlands	4.3	4.6	9.1	3.4	2.03	0.52	4.45	2.18
Austria	31.0	11.2	68.6	29.6	22.55	4.53	61.63	20.17
Poland	8.7	5.4	5.8	11.6	6.91	1.58	2.21	10.21
Portugal	24.41	3.89	37.56	37.95	19.21	0.42	27.39	32.50
Romania	22.16	1.30	30.89	26.43	16.81	1.82	28.43	17.34
Slovenia	20.76	2.25	33.76	28.87	18.40	0.85	29.27	22.82
Slovakia	9.37	5.36	17.77	8.18	6.39	1.50	15.40	5.06
Finland	31.20	4.56	27.35	42.89	29.23	1.01	26.71	39.50
Sweden	47.48	9.36	58.25	60.57	38.68	6.29	51.20	46.63

Source: Own elaboration based on Eurostat

According to the weighted product model (WPM), the total relative importance of alternative *i*, denoted as $QQ_i^{(2)}$, is defined as follows:

$$Q_i^{(2)} = \prod_{j=1}^{n} \left(\overline{x_{ij}}\right)^{w_j} \quad (4)$$

Assuming an increase in ranking relevance *i*, and, respectively, decision-making efficiency, a joint WSM and WPM criterion for determining the total importance of alternatives, called the weighted aggregate sum product assessment method (WASPAS), was proposed:

$$Q_j = \lambda \sum_{j=1}^{n} \overline{x_{ij}} w_j + (1 - \lambda) \sum_{j=1}^{n} \left(\overline{x_{ij}}\right)^{w_j}, \lambda = 0, \ldots . 1. \quad (5)$$

A value of λ = 0.5 was used to evaluate the development of renewable energy use in the EU-27 countries.

O_j takes values in the range [0, 1]. Higher values of alternatives indicate a more favorable solution.

The Shanon's entropy method was used to determine the weights of the assumed determinants. The algorithm for determining the weights in this method is as follows:

- to construct the decision matrix according to a given equation.
- to construct the normalized decision matrix:

$$x_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \quad (6)$$

- to determine entropy:

$$E_j = -k \sum_{t=1}^{m} x_{ij} \, ln(n_{ij}) \quad (7)$$

where:

$$k = -\frac{1}{ln(n)} \quad (8)$$

where:

n_{ij} is the proportion of samples in time *t* in the *i* indicator.

- to determine the variation level of entropy for each criterion (the degree of intrinsic divergence of scores from subsequent criteria) from equation:

$$d_j = 1 - e_j \quad (9)$$

- o determine the weights (degree of importance) of the criteria according to equation:

$$w_i = \frac{1 - E_j}{\sum_{j=1}^{n} (1 - E_j)} \quad (10)$$

RESULTS AND DISCUSSION

Based on the indicators adopted for the study, an assessment of the EU countries in terms of RES development for 2004 and 2019 was carried out.

The main research was preceded by the analysis of percentage changes in the use of energy from RES between 2004 and 2019.The results of this analysis are presented in Table 2.

Table 2 Percentage changes in renewable energy use rates between 2004 and 2019 (2004 = 100%)

	Change, %			
	RES share	**RES - Transport**	**RES - Electricity Generation**	**RES - Heating and Cooling**
Belgium	525.08	1165.75	1233.89	292.16
Bulgaria	233.60	812.87	281.28	252.61
Czechia	239.80	651.04	380.37	228.33
Denmark	250.70	1611.01	275.12	232.90
Germany	279.59	359.55	432.56	202.20
Estonia	173.41	2574.00	4028.94	157.11
Ireland	503.95	20300.00	605.07	219.87
Greece	274.78	4654.02	399.07	224.22
Spain	220.12	735.59	194.67	197.25
France	181.07	596.26	162.41	179.21
Croatia	121.63	587.85	142.13	125.12
Italy	287.59	745.84	216.14	344.49
Cyprus	449.37	-	51347.37	378.88
Latvia	124.95	239.08	116.24	135.95
Lithuania	147.83	907.85	523.84	155.56
Luxembourg	783.87	5547.10	392.66	477.94
Hungary	289.05	790.55	450.09	280.93
Malta	8321.57	-	-	2482.61
Netherlands	431.92	2428.74	409.78	325.11
Austria	149.09	215.51	121.93	167.61
Poland	175.93	387.03	649.84	156.58
Portugal	159.40	2143.63	196.33	128.13
Romania	144.49	431.34	146.72	148.46
Slovenia	119.44	939.18	111.49	140.90
Slovakia	264.34	553.87	142.47	389.10
Finland	147.38	2108.02	142.52	145.52
Sweden	145.80	482.01	139.05	141.79

Source: Own elaboration

Based on the calculations, the highest percentage increase in total renewable energy use between 2004 and 2019 was reported in Malta and Luxembourg. The lowest increase, on the other hand, was reported in Latvia and Croatia. However, it should be noted that Latvia and Croatia were already characterized by a significant level of RES use in 2004, and thus the increase in percentage terms is much lower than in the case of countries such as Malta, which practically did not use this energy at all. In terms of renewable energy use in transport, the largest increase was found in Ireland and the smallest in Austria. Malta and Cyprus were not included in this analysis as in 2004, the use of RES in transport in these countries amounted to 0%.

In the next stage of the research, based on the WASPAS calculations, the value of the ordering index Q_j was determined. The value of this index made it possible to rank the EU-27 countries in terms of RES development in 2004 and 2019. The results of the calculations for the two examined years (2004 and 2019) together with the position in the ranking are presented in Table 3.

Table 3 Ranking of the EU-27 countries in terms of RES development

	2004		2019	
	Q_j	Ranking	Q_j	Ranking
Belgium	0.088	24	0.116	24
Bulgaria	0.186	17	0.202	20
Czechia	0.177	19	0.209	18
Denmark	0.271	10	0.310	12
Germany	0.251	13	0.286	14
Estonia	0.197	16	0.243	17
Ireland	0.098	23	0.139	23
Greece	0.148	21	0.175	21
Spain	0.269	11	0.310	12
France	0.279	9	0.311	10
Croatia	0.396	6	0.388	7
Italy	0.244	14	0.291	13
Cyprus	0.064	25	0.109	25
Latvia	0.564	3	0.534	3
Lithuania	0.264	12	0.311	10
Luxembourg	0.062	26	0.091	26
Hungary	0.176	20	0.255	16
Malta	0.002	27	0.005	27
Netherlands	0.106	22	0.150	22
Austria	0.759	2	0.784	2
Poland	0.181	18	0.206	19
Portugal	0.437	5	0.506	5
Romania	0.343	8	0.347	8
Slovenia	0.370	7	0.395	6
Slovakia	0.231	15	0.255	16
Finland	0.497	4	0.523	4
Sweden	0.926	1	0.914	1

Source: Own elaboration

Based on the results, Sweden was found to be the leader and Austria the runner-up of the ranking. On the other hand, the final places were occupied by Luxembourg and Malta. Some countries improved their position in the ranking, such as Hungary (from 20 to 16), Slovenia (from 7 to 6) or Lithuania (from 12 to 10). Among the countries that recorded a decline were Poland (from 18 to 19), Bulgaria (from 17 to 20), and Croatia (from 6 to 7).

The value of the Q_j index also made it possible to assess the level of RES development in individual countries.

In order to assess the level of sustainable development of the EU-27 countries in terms of RES development, the following classes were distinguished:

I. Class I – high level of RES development:

$$Q_j > \overline{Q_j} + s_{Q_j} \tag{11}$$

II. Class II – average high level of RES development:

$$\overline{Q_j} + s_{Q_j} \geq Q_j > \overline{Q_j} \tag{12}$$

III. Class III – average low level of RES development:

$$\text{IV.} \quad \overline{Q_J} > Q_j \geq \overline{Q_J} - s_{Q_j} \tag{13}$$

IV Class IV – low level of RES development:

$$Q_j < \overline{Q_J} - s_{Q_j} \tag{14}$$

where:

$\overline{P_t}$ is the average value of Q_i and s_{Q_j} is the standard deviation of Q_j.

The division of the EU-27 countries into classes regarding the level of RES development is shown in Figures 1 and 2.

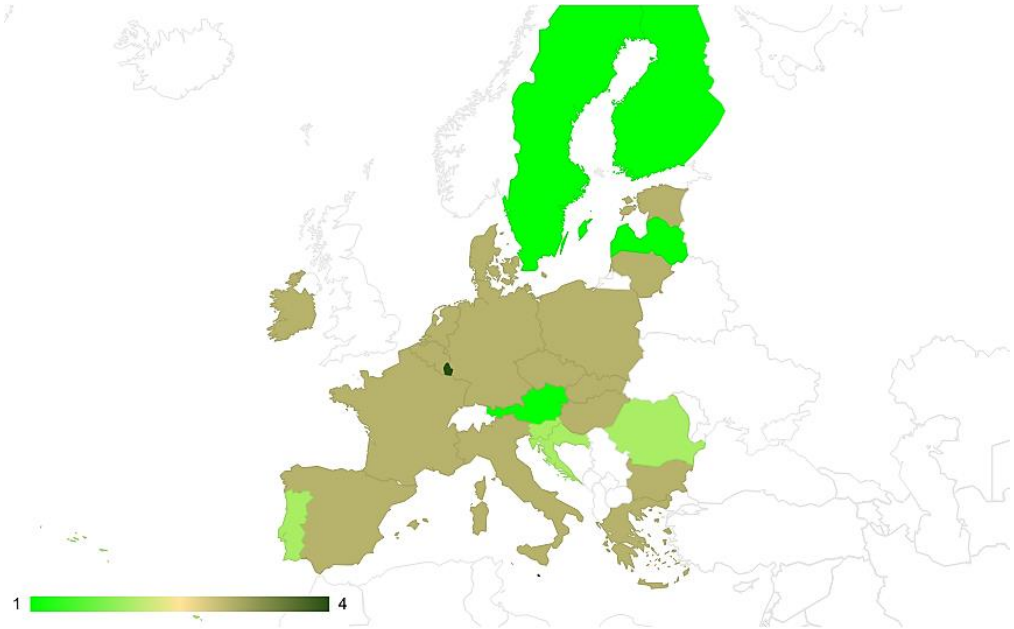

Fig. 1 Classes of the level of RES development in the EU-27 countries in 2004

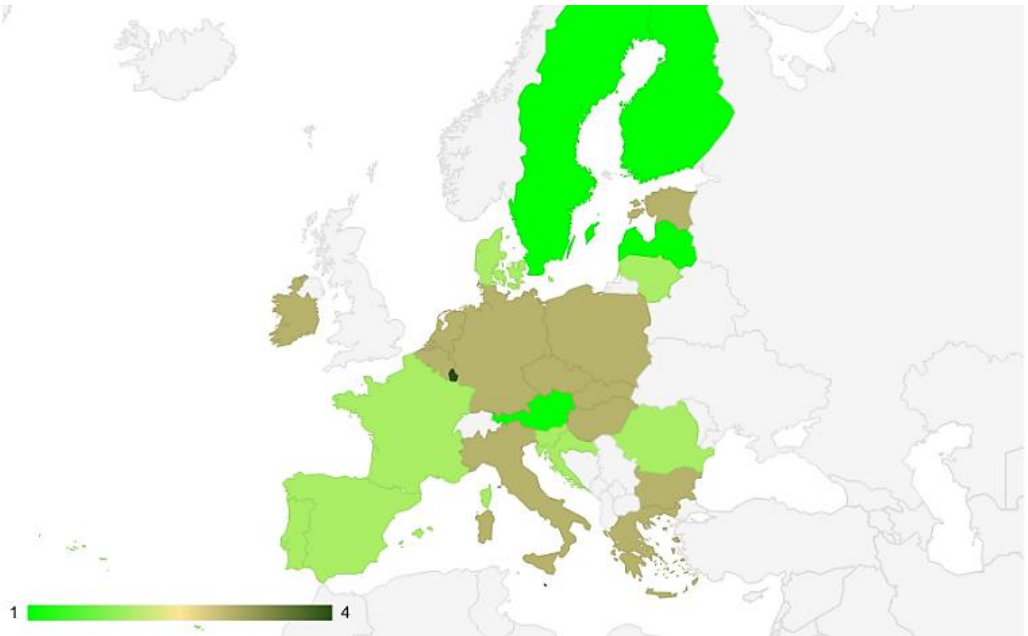

Fig. 2 Classes of the level of RES development in the EU-27 countries in 2019

The results showed that a high level of renewable energy use in both 2004 and 2019 was found in Sweden, Austria, Latvia and Finland. For 2004, the average high level was reported in Portugal, Croatia, Slovenia and Romania, and for 2019, in addition to these countries, also in Lithuania, France, Denmark, and Spain. The most numerous group comprised of countries characterized by an average low level. For 2004, these were France, Denmark, Spain, Lithuania, Germany, Italy, Slovakia, Estonia, Bulgaria, Poland, Czechia, Hungary, Greece, the Netherlands, Ireland and Belgium, and for 2019 – Italy, Germany, Slovakia, Hungary, Estonia, Czechia, Poland, Bulgaria, Greece, the Netherlands, Ireland, Belgium and Cyprus.

The low level of this development for 2004 was reported in Cyprus, Luxembourg and Malta, and for 2019, only in Luxembourg and Malta, as Cyprus is in the average low-level class.

Sweden, Austria, Latvia and Finland were shown to have a high level of RES use across the EU-27 in the studied period. Of these countries, only Austria failed to reach its 2020 RES targets (it was 0.6% short in 2019). The other countries, namely Sweden, Finland and Latvia, managed to achieve the target.

The undisputed leader of the ranking in this regard was Sweden, which has been developing RES since the 1970s and already in 2012 reached the targets set for 2020. In Sweden, more than 50% of energy used comes from RES. The country has combined high energy consumption with low carbon emissions. The most widely used RES in Sweden is water.

Also, Austria, Finland and Latvia have been developing RES for many years, which justifies their high ranking and high level of RES use in total and in transport or heating. In Austria, the most important RES is bioenergy, in Finland – Biofuel (wood) and in Latvia – hydropower and biomass. These countries have an extensive support and incentive package, which results in such a dynamic use of RES.

The worst situation in terms of RES-based energy was found in Luxembourg and Malta.

Malta, in general, is a country that has made great progress in the use of energy from RES. Although, for 2004 and 2019, it was the last country among all EU-27 countries in the overall ranking and its level of renewable energy use was assessed as low, the final energy consumption from RES increased from 0.10% in 2004 to 8.49%, in transport from 0% to 8.69% and in eclectic power generation from 0% to 8.04%. In heating and cooling, the share of energy consumption from RES increased from 1.04% to more than 25%.

Although Luxembourg has also made significant progress in the use of RES, like in the case of Malta, this progress was not significant enough versus the other EU countries to move up in the overall ranking. Luxembourg's progress in RES utilization is mainly due to the fact that the country signed an agreement with Lithuania, whereby energy from RES is "transferred" from Lithuania's to Luxembourg's register.

CONCLUSION

The purpose of the research was to assess the level of RES use in the EU-27 countries. Objective results could be obtained by using reliable tools by applying the MCDM method (WASPAS method). As a result, the EU countries were divided into four classes of the level of RES development for 2004 and 2019.

The results showed that a high level of RES utilization in both 2004 and 2019 was found in Sweden, Austria, Latvia and Finland. On the other hand, the low level of development for 2004 was found in Cyprus, Luxembourg and Malta and for 2019, in Luxembourg and Malta.

The study also showed that the share of RES in the final energy consumption of all EU member states has been increasing since 2004. This is due to the fact that in the analyzed 15-year period, these countries made huge investments in the development of RES, which was the result of the introduction of normative acts promoting these energy sources, among other activities.

Many countries, such as Sweden, Finland, Denmark, Estonia, Croatia, Lithuania, the Czech Republic or Slovakia, have already achieved their 2020 RES targets: Hungary and Estonia since 2011, Sweden and Bulgaria since 2012, the Czech Republic since 2013, and Romania, Lithuania, Italy and Finland since 2014.

Countries that have not reached this target include France, Poland, Spain, Slovenia, Malta, and Luxembourg. Therefore, it is clear that many EU countries need to increase their share of RES to reach their national energy consumption targets in line with the EU strategy.

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Abstract: Energy security is one of the basic tasks carried out by individual countries. It is of great socio-economic and political importance and constitutes the basis for independent development of both economies and groups of countries. Access to adequate resources of affordable and environmentally neutral energy in the production process is the basis for sustainable energy development. Therefore, an important element of sustainable energy is its environmental neutrality. Currently, this condition is fulfilled to the greatest extent by energy produced from renewable energy sources (RES). Renewable energy development is taking place all over the world, but the European Union (EU) is a definite leader. In its energy policy, the importance and role of RES in the energy production structure has been growing systematically for many years. Introduced regulations and energy strategies caused member states to take extensive actions to achieve the set targets for RES. However, the large diversity of the EU countries makes this process occur with different intensity. Thus, it was justified to conduct research to assess the level of renewable energy use in the EU countries in a 15-year perspective (2004-2019). The research was based on a set of 4 indicators characterizing the use of renewable energy in the EU countries by means of the WASPAS method (from the group of MCDM methods). The results showed that a high level of RES use in the whole studied period was found in Sweden, Austria, Latvia and Finland, and a low level, for 2004, was found in Cyprus, Luxembourg and Malta, and for 2019 – in Luxembourg and Malta.

Keywords: European Union, renewable energy, RES, sustainable development, WASPAS method, MCDM method