Chapter 2

Economic Evaluation of Renewable Energy Performance of European Union Countries and Türkiye with the Multi-Criteria Decision-Making Methods

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Abstract

This study uses a thorough multi-criteria decision-making (MCDM) framework to assess and compare the renewable energy performance of Türkiye and 26 other EU nations. The purpose of this study is to evaluate how well these nations have advanced during 2015, 2020, and 2023 in their transition to sustainable energy. To represent the multifaceted nature of the performance, twelve quantitative variables pertaining to the production, consumption, efficiency, and dependency of renewable energy were used. Three well-known techniques—CRITIC, LOPCOW, and Standard Deviation—were used to compute weighting coefficients in order to impartially assess the relative significance of these variables. The rankings of countries were then obtained using five different MCDM procedures (ARAS, COPRAS, CRADIS, GRA, and TOPSIS), which were then combined using the BORDA aggregation method to get a final comprehensive rating. The findings show a constant pattern of leadership, with Sweden, Finland, Denmark, Germany, and Austria leading the pack. This trend is ascribed to the consistency of policies, the ability to innovate, and the successful integration of renewable energy sources into national grids.

On the other hand, due to institutional fragmentation, financial limits, and structural limitations, Eastern and Southern European nations fare

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comparably poorly to Türkiye. However, Türkiye's score shows steady progress over time and increasing potential with the right policy alignment. Overall, the results indicate that Europe's renewable energy landscape remains divided along North-South and West-East lines. To support a more equitable and balanced transition to renewable energy across the continent, the report emphasizes the need for long-term policy stability, regional cooperation, grid modernization, and inclusive funding mechanisms.

1. Introduction

Energy is a prerequisite for economic activities in all developed and developing countries. Today, production without energy resources is impossible. Energy, a crucial input for economic growth and development, has become a significant topic on the global agenda today.

Recently, significant ruptures have been observed in the energy paradigm. A transition from an economic order dominated by fossil fuels to a sustainable energy order, driven by energy security and climate change, is underway. The rapid increase in global population and the rising demand for fossil resources brought about by industrialization have introduced concepts such as environmental degradation and climate change into our lives. The concept of energy security, which refers to the uninterrupted and clean supply of energy at reasonable prices, has recently become a concern in our lives, particularly due to concerns about the depletion of fossil resources and the frequent global imbalances.

The dominance of fossil fuels has shaped the global energy cycle since the Industrial Revolution. Resources such as coal, oil, and natural gas meet a significant portion of the world's energy needs. However, this energy cycle has two fundamental limitations. First, these resources are non-renewable and in danger of depletion. Second, greenhouse gas emissions resulting from their combustion trigger global climate change (Sağır, 2024). These two critical problems have led to a questioning of the current energy paradigm and necessitate a transformation.

Renewable energy is provided from naturally occurring sources, such as the sun, wind, and rivers, and is inexhaustible and self-renewing. Three main characteristics distinguish renewable energy from non-renewable sources. The first is the absence of concerns about depletion. Second, these resources are mainly independent of external sources. Finally, the generation of energy from these resources has virtually no negative environmental impact.

Renewable energy plays an essential role in the economy-energy-environment triangle. In the process that began with industrialization and continued with the rapid increase in global population, fossil resources became indispensable to the economy. However, a dilemma arises when considering their adverse environmental effects. The transition to renewable energy has become an environmental imperative and a transformative force, spurring a new growth and development model for both global and local economies. Renewable energy investments directly contribute to economic growth by encouraging the construction of new facilities and reducing external dependency (Pao and Fu, 2013; Ntanos et al., 2018; Kasperowicz et al., 2020; Saidi and Omri, 2020). The renewable energy sector provides new employment opportunities. According to the report of the International Renewable Energy Agency (2024), worldwide employment in the renewable energy sector reached 16.2 million in 2023. Another advantage of renewable energy as a domestic resource is that it can reduce the foreign trade deficit caused by this dependence on foreign energy. The fact that renewable resources are domestic and do not create dependency on foreign sources due to their consumption contributes to the reduction of energy imports in economies (Gökce ve Demirtaş, 2018; Bildirici ve Kayıkçı, 2022; Ozkan ve Okay, 2024).

Another advantage of renewable energy in addressing the dilemma between the use of fossil resources and the economy and the environment is its economic sustainability. Concerns about the depletion of fossil resources are increasing daily. According to the Energy Institute's (2025) report, by the end of 2024, the remaining life of oil worldwide is 53.5 years, that of natural gas is 48.8 years, and the remaining life of coal is 139 years. According to this report, alternatives to fossil resources, such as oil, natural gas, and coal, must be prepared. From this perspective, renewable energy is a vital alternative for achieving sustainable growth and development.

In addition to all the above, renewable energy plays a crucial role in combating climate change. Renewable energy plays a key role in achieving the climate change and environmental sustainability goals of global actors. Less environmental degradation is possible by expanding the consumption of renewable resources. According to the IEA (2025) report, energy-related CO_2 emissions in developed economies decreased by 1.1% in 2024, primarily due to the widespread adoption of renewable energy in these regions.

In the application part of the study, the European Union, which includes both developed and developing countries, and Türkiye, one of the European Union candidate countries, were discussed. This sample was chosen for two primary reasons. The first is that EU countries and Türkiye are highly dependent on fossil resources from foreign sources. The second is the country's efforts to eliminate the disadvantages of foreign dependency on fossil resources by utilizing domestic and renewable resources. Therefore, evaluating the potential of renewable resources is indispensable for EU countries and Türkiye.

Renewable energy sources offer significant macroeconomic advantages for EU countries and Türkiye. Contribution to the current account balance by reducing external dependency, increasing energy security, promoting economic growth and employment, creating new investment opportunities, and enhancing export potential can be considered the main macroeconomic advantages. From this perspective, renewable energy is an environmental necessity and a strategic policy argument regarding economic independence and sustainable growth potential.

Table 1 shows the energy import dependencies of EU countries and Türkiye as a percentage. These countries are also used as samples in the application part of the study. Looking at the EU, external dependency is expected to be 58.3% by 2023. This figure is 62.5% in 2022. In other words, the EU imports approximately 60% of the energy it consumes. We consider this rate relatively high for European Union countries. This rate is even higher in developed economies such as Belgium, Germany, Greece, Italy, the Netherlands, and Spain (76.1%, 66.4%, 75.6%, 74.8%, 70.4%, and 68.4%, respectively). Developing economies, such as Hungary and Türkiye, also have import dependency rates higher than the EU average. However, France, Poland, and Romania are examples of countries with lower import dependency than the EU average.

This study aims to assess the renewable energy performance of the EU and Türkiye within the framework of the figures and explanations provided above. We aim to contribute to energy policies by measuring renewable energy performance. In the application part of the study, Malta, a member of the EU, was excluded from the sample because some of its data could not be accessed. This situation constitutes one of the study's limitations. Another limitation of the study is that the findings are valid within the framework of the method used. Future studies can investigate the subject using different samples, time periods, and techniques.

Within the framework of the figures and explanations above, this study aims to reveal the renewable energy performance for the EU and Türkiye. We aim to contribute to energy policies by measuring the performance of renewable energy using some MCDM methods. In the application part of the study, Malta, a member of the EU, was excluded from the sample because some of its data could not be accessed. This situation constitutes one of the study's limitations. Another limitation of the study is that the findings are valid within the framework of the method used. Future studies can investigate the subject using different samples, time periods, and techniques.

Table 1: Energy import dependency (%) (EU and Türkiye)

	2020	2021	2022	2023
European Union - 27 countries	57.5	55.5	62.5	58.3
Austria	58.4	51.8	74.2	61.1
Belgium	78.1	70.9	74.0	76.1
Bulgaria	38.2	36.2	37.1	39.7
Croatia	53.6	54.5	60.3	55.7
Cyprus	93.2	89.5	92.0	92.2
Czechia	38.8	40.0	41.8	41.7
Denmark	44.9	32.2	42.8	38.9
Estonia	10.5	1.4	6.2	3.5
Finland	43.0	37.9	40.9	29.6
France	44.4	44.1	51.9	44.9
Germany	63.7	63.4	68.6	66.4
Greece	81.4	73.8	79.6	75.6
Hungary	56.6	54.1	64.2	62.1
Ireland	71.1	77.0	79.2	77.9
Italy	73.5	73.3	79.2	74.8
Latvia	45.5	38.3	38.2	32.7
Lithuania	74.9	73.3	72.4	68.0
Luxembourg	92.3	92.5	91.5	90.6
Netherlands	68.0	58.4	80.2	70.4
Poland	42.8	40.5	46.0	48.0
Portugal	65.3	66.9	71.3	66.9
Romania	28.2	31.6	32.4	27.9
Slovakia	56.3	52.6	69.6	57.7
Slovenia	45.7	48.6	53.9	49.3
Spain	67.9	69.4	74.4	68.4
Sweden	32.0	21.2	27.0	26.4
Türkiye	70.6	70.9	67.3	67.9

Source: Eurostat dataset

The ranking of the alternatives in the relevant year is usually determined using data from a single year in MCDM analysis. In this instance, information regarding the alternatives' prior standing is absent from the rankings for that year. For example, it is impossible to determine whether an option that came in third place that year improved from 12th to third or from first to third in a single-year comparison of 12 alternatives. The use of three datasets covering specified intervals—2015, 2020, and 2023—to ascertain the advancement of nations during the pertinent era is one of the study's unique features. Data beyond this year is not accessible.

Additionally, the full effects of a nation's renewable energy regulations take time to manifest and show up in the performance of that nation's renewable energy sector. We can observe the performance of the countries during the relevant period because the data used in the study spans three distinct years with precisely defined intervals. The following succinctly describes this study's novelty and literary contribution:

• While there are very few studies analyzing renewable energy performance using MCDM methods, there is no study that ranks countries based on renewable energy performance using different weighting and ranking methods simultaneously.

• No study ranks European Union countries based on their renewable energy performance.

• This study uses the most criteria in renewable energy performance analysis. In this respect, it can inspire future studies.

• The study examined the renewable energy performance of countries from a multifaceted perspective, considering different dimensions such as production, consumption, and self-sufficiency of energy provided by different sources, not just a single source.

• Unlike other studies, this study used three separate data sets, spanning approximately five years, rather than just one year of data. This method provided the opportunity to observe changes in renewable energy performance over time from a comparative static analysis perspective.

The following sections of the study comprise the literature review. We will examine previous studies on this subject. Secondly, the section explaining the data and methodology used in the study is included. Thirdly, the study's empirical findings are analyzed in the findings section. Finally, the conclusion section is included, the study is discussed, and policy recommendations are provided.

2. Literature Review

In this section of the study, we will examine previous studies on this subject in the literature. A comparison will be made between the studies in the literature and this study on their similarities and differences. Studies in the literature will be categorized into two groups. The first group will include studies on measuring renewable energy performance in Türkiye and the EU using the MCDM method. In the second group, studies on the performance of renewable energy in other countries will be examined.

Studies on renewable energy are particularly popular in countries that must import energy, as it is one of the fundamental inputs for sustainable growth and development. In the first group, studies on the performance of renewable energy in Türkiye and later in EU countries will be discussed. Among these studies, Uysal (2011) and İskender (2015) can be cited as examples of research that measure renewable energy performance using various methods. In her study, Uysal (2011) evaluated renewable energy alternatives in terms of energy investments in Türkiye using graph theory and matrix approach. İskender (2015) examined the performance of renewable energy use for thirty countries, including Türkiye, between 2000 and 2009 using the Window analysis method. Studies on measuring renewable energy performance in Türkiye have been shaped within the framework of MCDM analysis. Examples of these studies are: Aydın & Kaçtıoğlu (2024), Dumrul et al. (2024), Özcan et al. (2022), Kısa (2021), Albayrak (2020), Derse and Yontar (2020), Karaaslan and Aydın (2020), Aksoy (2019), Değirmenci et al. (2018), Engin et al. (2018), Büyüközkan and Güleryüz (2017), Çolak and Kaya (2017), Karaca et al. (2017), and Kabak and Dağdeviren (2014). Upon examining these studies, it became apparent that different results emerged. Kabak and Dağdeviren (2014), Karaaslan and Aydın (2020), Karaca et al. (2017), and Derse and Yontar (2020) concluded that hydroelectric energy is the most optimal among renewable energy sources for Türkiye, based on their studies. In their studies, Çolak and Kaya (2017) and Özcan et al. (2022) concluded that wind energy is a more efficient source of energy. Dumrul et al. (2024) and Uysal (2011) reached a similar conclusion in their studies, stating that solar energy would be more efficient than renewable sources for Türkiye. Aksoy (2019) developed different results and suggestions for other regions in her study. Unlike other studies, Büyüközkan and Güleryüz (2017) suggested geothermal energy for Türkiye.

Menegaki (2013), Matsumoto et al. (2020), Tutak (2021), and Ozsoy et al. (2024) are examples of studies on the renewable energy performance of the European Union. Matsumoto et al. (2020) determined the environmental performance and renewable energy performance of EU countries using a different method in their study. Menegaki (2013) employed data envelopment analysis to assess the efficiency of renewable energy performance in 31 European countries from 1997 to 2010. Tutak (2021) evaluated the level of use of renewable energy sources (RES) in EU-27 countries using the MCDM technique. Ozsoy et al. (2024) assessed the renewable energy preferences of European countries and Türkiye in the 2010-2020 period using multi-criteria decision-making methods (MCDM). The study by Ozsoy et al. (2024) is similar to this study in terms of sample. For this reason, the following sections of the study will discuss the similarities and differences between this study and the studies of Ozsoy et al. (2024).

Finally, studies examining samples outside the EU and Türkiye will be discussed among studies on measuring renewable energy performance. Al Garni et al. (2016) discussed Saudi Arabia as a country that should prioritize renewable resources, despite being an oil-producing nation. According to the MCDM analysis, solar energy is the most effective renewable resource for Saudi Arabia. In another study, Lee and Chang (2018) tried to determine the best renewable resource for Taiwan with MCDM analysis. Sadeghi et al. (2025) stated in their study for Ghana that hydroelectricity is the most optimal choice, as determined by MCDM analysis. Moreno-Rocha et al. (2025) made a similar analysis for Colombia and made regional recommendations.

3. Data and Methodology

3.1. Data

This study used a combination of weighting and ranking techniques to compare the renewable energy performance of the European Union and Türkiye. The objective weights of the criteria are provided by the CRITIC, Standard Deviation, and LOPCOW methods. Each country's renewable energy performance is measured and ranked using the ARAS, COPRAS, CRADIS, GRA, and TOPSIS Methods. The dataset's sources are the European Statistical Office (Eurostat) and the Energy Institute. To assess how performance has shifted over time, calculations have been conducted using 12 renewable energy performance criteria for each country in 2015, 2020, and 2023.

The criteria listed below are utilized to evaluate the country's performance in renewable energy: primary energy consumption, per capita (Gigajoule/Population), electricity generation, per capita (Terawatt-hours/Population), solar consumption, per capita (Exajoules/Population), solar generation, per capita (Terawatt-hours/Population), wind consumption, per capita (Exajoules/Population), wind generation, per capita (Terawatt-hours/Population), geothermal, biomass and other renewable consumption, per capita (Exajoules/Population), geothermal, biomass and other renewable generation, per capita (Terawatt-hours/Population), hydro consumption, per capita (Exajoules/Population), hydro generation, per capita (Terawatt-hours/Population), share of energy from renewable sources (renewable sources consumption / gross final energy consumption) (%), energy imports dependency ((imports – exports) / gross available energy) (%).

The parameters used in this study cover a wide range of renewable energy areas, including efficiency, external dependency, production, and consumption capacities. Therefore, this study will rank countries based on their renewable energy performance, considering all aspects of renewable energy, rather than just their renewable production levels. Table 2 lists the renewable performance criteria, their abbreviations, guidelines, and sources.

Table 2: Criteria, Abbreviations, and Directions

No.	Criteria	Abbreviation	Direction	Source
1	Primary Energy Consumption, Per Capita (Gigajoule/Population)	PEC	Maximum	Energy Institute
2	Electricity Generation, Per Capita (Terawatt-hours/Population)	EG	Maximum	Energy Institute
3	Solar Consumption, Per Capita (Exajoules/Population)	SC	Maximum	Energy Institute
4	Solar Generation, Per Capita (Terawatt-hours/Population)	SG	Maximum	Energy Institute
5	Wind Consumption, Per Capita (Exajoules/Population)	WC	Maximum	Energy Institute
6	Wind Generation, Per Capita (Terawatt-hours/Population)	WG	Maximum	Energy Institute
7	Geothermal, Biomass and Other Renewable Consumption, Per Capita (Exajoules/Population)	GEOC	Maximum	Energy Institute
8	Geothermal, Biomass and Other Renewable Generation, Per Capita (Terawatt-hours/Population)	EMI	Minimum	Energy Institute
9	Hydro Consumption, Per Capita (Exajoules/Population)	HC	Maximum	Energy Institute
10	Hydro Generation, Per Capita (Terawatt-hours/Population)	HG	Maximum	Energy Institute
11	Share of energy from renewable sources (%)	SRES	Maximum	Eurostat
12	Energy imports dependency (%)	EID	Minimum	Eurostat

Source: Energy Institute, Eurostat

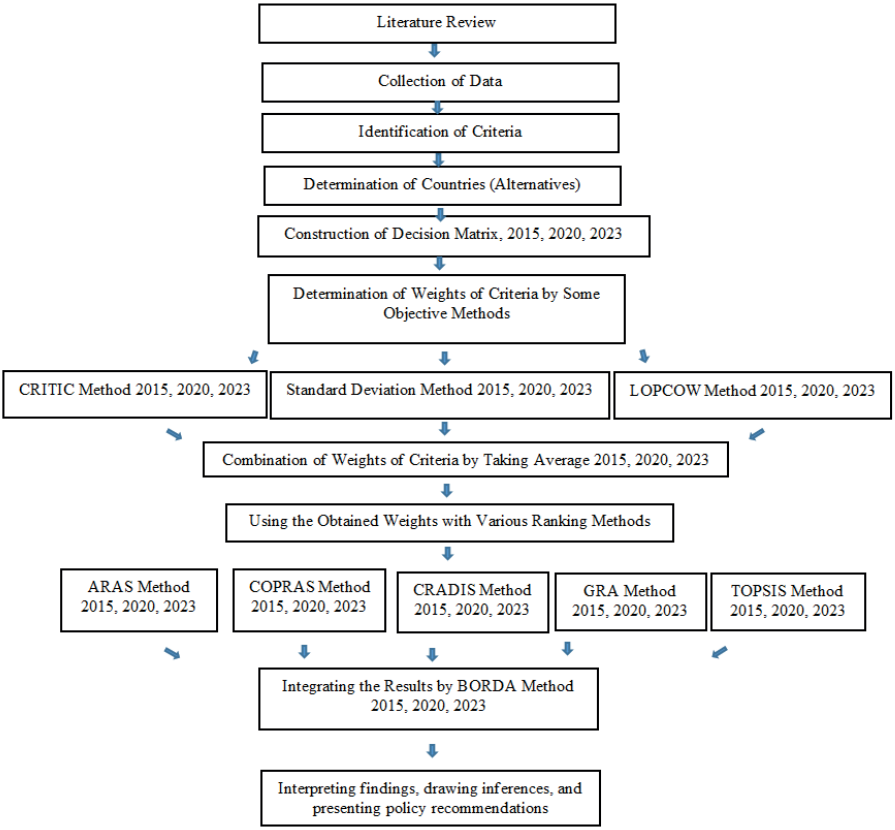
Table 2 shows the 12 criteria used in the study. We have previously revealed the high import dependency of the EU and Türkiye on energy. Criterion 12 illustrates this import dependency, and a lower value indicates a reduced external dependency, thereby indicating good performance of renewable resources. The importance of renewable energy policies in reducing dependency on fossil fuels for imports is obvious. Criteria 3, 4, 5, 6, 7, 8, 9, and 10 illustrate the production and consumption values of renewable resources, including solar, wind, geothermal, biomass, and hydro. The high level of these values indicates that renewable energy performance is increasing. Criterion 11 shows the share of renewable resources in total energy consumption and is one of the main criteria. An increase in criterion number 11 indicates that the performance of renewable energy is improving. Criterion 1 indicates primary energy consumption per capita, while Criterion 2 indicates electricity production per capita. An increase in criteria 1 and 2 signals a rise in energy demand. Since the EU and Türkiye have high energy import dependency, an increase in criteria with the numbers 1 and 2 is negative for these countries. However, if criteria 1 and 2 increase and criteria 3, 4, 5, 6, 7, 8, 9, and 10 also increase, renewable resources will meet the increasing energy demand.

Benefit criteria with the numbers 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, and 11 are those listed in Table 2. The greater the performance score, the higher the criterion value. The performance score is inversely proportional to the cost criterion value of 12, with lower cost values yielding higher scores.

3.2. Methodology

Different weight coefficients can yield different solutions during the MCDM process. It's interesting to investigate strategies for creating weight coefficient combinations with good performance. A decision-maker must be involved in subjective approaches. Therefore, when there are no subjective preferences among the objectives, an objective process that excludes the subjective input of a decision-maker is required (Fan et al. 2022). The CRITIC, LOPCOW, and Standard Deviation methods were used to determine the objective weights of the criteria in this study. These weights were then averaged for 2015, 2020, and 2023 before being combined. As a result, criterion weights that were more realistic and resilient were developed. Each year, the TOPSIS, CRADIS, GRA, COPRAS, and ARAS ranking algorithms will be applied using the average weights derived from the previously described techniques. The rankings produced by these five methods will then be combined using the BORDA method to provide a single ranking for every year. A flowchart of the study's approach is displayed in Figure 1.

Figure 1: Flowchart of the Methodology used in the study



Every technique used to rank alternatives and establish criteria weights has unique features and computation procedures. This task will be greatly accelerated by referring to the investigations and solution steps from whence each mathematical approach originated, rather than outlining each one separately. This will enable a stronger focus on renewable energy. A strong objective weighting framework for MCDM is the CRITIC (Criteria Importance Through Intercriteria Correlation) methodology, first proposed by Diakoulaki et al. (1995). In contrast to subjective methods, it minimizes potential bias by determining criterion weights only from the dataset's inherent statistical properties (Mardani et al., 2015; Zardari et al., 2015). To be more precise, the approach operationalizes two core ideas: inter-criterion conflict and contrast intensity. Because greater dispersion indicates stronger selective power, criteria that show significant heterogeneity among options are therefore given additional weight (Kou et al., 2016).

On the other hand, a criterion's informational contribution is deemed redundant when it exhibits substantial association with other criteria; as a result, it is given a comparatively lower weight (Çelikbilek and Tüysüz, 2016). In practice, correlation coefficients are used to measure the degree of conflict, while the standard deviation of each criterion is used to quantify the degree of contrast (Diakoulaki et al., 1995). As a result, the CRITIC approach enables a weighting procedure that simultaneously considers the uniqueness and variability of criteria, yielding objective and data-driven weights that enhance the resilience of MCDM applications (Wang and Luo, 2010; Wu et al., 2011).

The Logarithmic Percentage Change-Driven Objective Weighting (LOPCOW) approach was created by Pamučar and Ecer (2022) as an objective weighting technique to determine the relative relevance of factors in MCDM. Because LOPCOW uses the dataset to generate weights, it is less biased and more objective than subjective approaches that rely on expert judgment. The method applies a logarithmic percentage change function to normalized performance data, capturing the degree of variation and information content for each criterion. Consequently, criteria with higher discriminatory power among alternatives are given more weight than those with lower variability.

Yamamoto (1974) was the first to employ Standard Deviation as an objective criterion weighting technique in MCDM. Yamamoto maintained that indicators should be assigned higher weights since they transmit more information when there is greater variety between alternatives. Dispersion-based objective weighing originated from this basic concept.

The ARAS methodology was developed by Zavadskas and Turskis in 2010 as the MCDM method. In the ARAS (Additive Ratio Assessment) method, the benefit function value, which determines the complex relative effectiveness or efficiency of an alternative, is directly proportional to the relative impact of the primary criteria values and weights considered in an application (Zavadskas and Turskis, 2010:163).

When considering multiple attributes, the proper technique, Complex Proportional Assessment (COPRAS), is typically employed. Determining the relative weight and utility of each choice is the main objective of COPRAS, by transforming this utility into a ranking of all the options, the most beneficial one can be selected. (Patil et all., 2022). As an MCDM technique, COPRAS was first presented by Zavadskas and Kaklauskas (Zavadskas and Kaklauskas, 1996). Since the COPRAS methodology yields more precise information than other approaches for analyzing the cost or benefit criteria, it assumes both elements of the criteria. Additionally, COPRAS simultaneously shows the ratios to the best and worst solutions (Mishra et al., 2022:2).

Puška et al. (2021) created a new MCDM technique called the CRADIS method. The goal of the CRADIS technique is to determine the degree to which options deviate from the ideal and anti-ideal solutions. This method incorporates aspects of the ARAS (Additive Ratio Assessment), TOPSIS, and MARCOS (Measurement Alternatives and Ranking according to Compromise Solut) approaches. The CRADIS method is a distinctive approach to integrating aspects of various systems, although it is not a completely novel strategy. Ideal solutions, which display the alternative's maximum value when considered from every angle, are used in this method. Put differently, the minimum value of the ideal solution (Puška et al., 2021:11204).

GRA (Grey Relational Analysis) is a classification, ranking, and decision-making technique that has become a subcategory of the grey system theory in scientific research. In 1982, Julong Dang's "Control Problems of Gray Systems" was the first paper in Thailand to put forth the grey theory. Grey relational analysis, grey modeling, grey estimating, and grey decision-making are only a few of the subheadings in the literature that apply the gray theory (Dinçer, 2019:61).

Hwang and Yoon first presented TOPSIS (Technique for Preference by Similarity to the Ideal Solution) as a multi-criteria decision-making approach in 1981. Later, Yoon and Hwang (1995) and Lai et al. (1994) improved this method. This method's guiding assumption is that, in terms of geometry, the best choice should be the one that is farthest from the negative ideal solution and closest to the perfect solution. In other words, the ideal alternative has the maximum level of all the traits considered, whereas the negative ideal is the option with the lowest attribute value.

Jean-Charles de Borda proposed a solution to the ranking issues in voting results in 1781 (Newenhizen, 1992:70). In the BORDA method, voter rankings are converted into scores using weights for the ranks, a type of preference voting. Society's choice for alternatives is determined by the order in which each option earns a score. The societal preference order can be ascertained by using any set of weights w1≥ w2 ≥ ….≥ wn as the weights for ranks 1, 2, 3, …, rank n. Multiple weight systems can produce different society preference orders for a given set of voter preference orders. The weighted technique can also be used to choose the winners or losers of an election; the best option is considered the winner, and the worst option is considered the loser (Rao and Kopparty, 2015).

4. Findings

This study compared Türkiye's and the EU-26 countries' renewable energy performance using 12 parameters using a combination of weighting and ranking approaches. The LOPCOW, CRITIC, and Standard Deviation approaches provide the criteria's objective weights. Using the ARAS, COPRAS, CRADIS, GRA, and TOPSIS Methods, the performance of each nation in terms of renewable energy is evaluated and ranked. Afterwards, the BORDA approach incorporated the results. Calculations have been performed to analyze how each country's performance has evolved over time, using 12 renewable energy performance parameters for each country in 2015, 2020, and 2023.

4.1. Results of the Weighting Methods

A decision matrix was developed for each approach at the beginning of the study to rank the alternatives and establish the criteria weights. Table 3 presents the average results for 2015, 2020, and 2023, derived from the three distinct objective criterion weighting techniques employed in the study.

Table 3: Importance levels of criteria by different weighting methods, 2015, 2020, 2023

Criteria	**CRITIC**	**LOPCOW**	**Standard Deviation**	**Average**	**Rank**
2015					
PEC	0.092103	0.109687	0.085779	0.095856	3
EG	0.053306	0.128261	0.073023	0.084863	6
SC	0.133335	0.074169	0.076860	0.094788	4
SG	0.133335	0.074169	0.076860	0.094788	5
WC	0.076693	0.069691	0.078801	0.075062	8
WG	0.076693	0.069691	0.078801	0.075062	7
GBOC	0.057978	0.057792	0.098700	0.071490	9
GBOG	0.057986	0.058162	0.098071	0.071407	10
HC	0.063844	0.034638	0.074997	0.057826	12
HG	0.063844	0.034638	0.075017	0.057833	11
SRES	0.077095	0.126007	0.085285	0.096129	2
EID	0.113787	0.163096	0.097807	0.124897	1
2020					
PEC	0.089795	0.101720	0.081489	0.091001	4
EG	0.054408	0.104570	0.077117	0.078698	8
SC	0.128734	0.105198	0.079240	0.104390	2
SG	0.128734	0.105198	0.079240	0.104390	3
WC	0.084369	0.074569	0.080583	0.079840	6
WG	0.084369	0.074569	0.080583	0.079840	7
GBOC	0.062612	0.063779	0.093922	0.073438	10
GBOG	0.062598	0.064448	0.093947	0.073664	9
HC	0.069965	0.033681	0.079128	0.060925	11
HG	0.063814	0.030516	0.079156	0.057829	12
SRES	0.072227	0.085678	0.088117	0.082008	5
EID	0.098374	0.156074	0.087480	0.113976	1
2023					
PEC	0.090403	0.114395	0.075289	0.093362	4
EG	0.055141	0.101246	0.074494	0.076960	8
SC	0.128428	0.109811	0.082660	0.106966	3
SG	0.128428	0.109811	0.082660	0.106966	2
WC	0.081420	0.072653	0.083630	0.079234	6
WG	0.081420	0.072653	0.083630	0.079234	7
GBOC	0.057891	0.061058	0.083549	0.067499	10
GBOG	0.057960	0.061714	0.083599	0.067758	9
HC	0.077549	0.036683	0.082153	0.065462	12
HG	0.077549	0.036684	0.082177	0.065470	11
SRES	0.067378	0.086462	0.087774	0.080538	5
EID	0.096432	0.136829	0.098388	0.110549	1

PEC: Primary Energy Consumption, Per Capita (Gigajoule/Population), **EG**: Electricity Generation, Per Capita (Terawatt-hours/

Population), **SC**: Solar Consumption, Per Capita (Exajoules/Population), **SG**: Solar Generation, Per Capita (Terawatt-hours/Population), **WC**: Wind Consumption, Per Capita (Exajoules/Population), **WG**: Wind Generation, Per Capita (Terawatt-hours/Population), **GBOC**: Geothermal, Biomass and Other Renewable Consumption, Per Capita (Exajoules/Population), **GBOG**: Geothermal, Biomass and Other Renewable Generation, Per Capita (Terawatt-hours/Population), **HC**: Hydro-Consumption, Per Capita (Exajoules/Population), **HG**: Hydro-Generation, Per Capita (Terawatt-hours/Population), **SRES**: Share of Energy from Renewable Sources (%), **EID**: Energy Import Dependency (%).

The criteria weights were independently determined using the data in the decision matrix and the CRITIC, LOPCOW, and Standard Deviation procedures. They were then combined by figuring out their averages. In 2015, energy import dependency was the most heavily weighted criterion at 12.4%, while hydro-generation per capita was the least at 5.7%. The greatest weighted criterion for 2020 and 2023, respectively, was found to be energy import dependency, with 11.3% and 11%. With 5.7% for 2020 and 6.5% for 2023, respectively, hydro-generation and hydro-consumption per capita are the lowest weighted criteria.

4.2. Results of Ranking Methods

Five distinct MCDM methods—TOPSIS, CRADIS, GRA, COPRAS, and ARAS—were employed to evaluate the renewable energy performance of EU-26 countries and Türkiye, utilizing data from 2015, 2020, and 2023. The rankings were then combined using the BORDA integration method to create a single final ranking, which is shown in Tables 4, 5, and 6, respectively.

Table 4: Rankings of Counties by Different MCDM Methods, 2015

Countries	TOPSIS	CRADIS	GRA	COPRAS	ARAS	BORDA
Austria	6	6	6	5	5	5
Belgium	8	9	12	8	9	9
Bulgaria	17	13	13	15	15	14
Croatia	23	22	21	22	22	22
Cyprus	16	25	26	23	25	23
Czechia	13	10	7	12	11	11
Denmark	4	2	2	3	3	3
Estonia	14	5	5	9	6	7
Finland	2	3	3	2	2	2
France	19	17	16	18	16	18
Germany	3	4	4	4	4	4
Greece	9	11	10	10	10	10
Hungary	26	26	23	27	26	26
Ireland	12	19	20	16	18	17
Italy	5	8	8	6	8	6
Latvia	18	21	19	21	21	20
Lithuania	21	24	24	24	24	25
Luxembourg	11	15	11	13	17	13
Netherlands	20	18	15	19	19	19
Poland	27	23	18	25	23	24
Portugal	10	12	17	11	12	12
Romania	25	14	9	17	13	15
Slovakia	22	20	25	20	20	21
Slovenia	15	16	22	14	14	16
Spain	7	7	14	7	7	8
Sweden	1	1	1	1	1	1
Türkiye	24	27	27	26	27	27

The top nations with the best renewable energy performance, according to BORDA statistics, are Sweden, Finland, Denmark, Germany, and Austria. Italy, Estonia, Spain, Belgium, Greece, Czechia, Portugal, Luxembourg, Bulgaria, and Romania are notable examples of medium-performing nations, with rankings ranging from sixth to fifteenth. Countries that rank between 16th and 27th, including France, the Netherlands, Latvia, Slovakia, Croatia, Cyprus, Poland, Lithuania, Hungary, and Türkiye, can be categorized as low-performing.

Table 5: Rankings of Counties by Different MCDM Methods, 2020

Countries	TOPSIS	CRADIS	GRA	COPRAS	ARAS	BORDA
Austria	5	7	8	3	5	5
Belgium	7	8	7	7	8	8
Bulgaria	20	18	17	18	18	18
Croatia	24	21	23	19	19	21
Cyprus	15	24	24	24	26	22
Czechia	17	16	14	17	17	16
Denmark	4	4	4	6	6	4
Estonia	11	5	5	5	3	6
Finland	2	2	2	2	2	2
France	18	15	15	16	16	15
Germany	3	3	3	4	4	3
Greece	9	11	13	12	12	11
Hungary	19	19	20	23	23	19
Ireland	13	14	12	14	14	14
Italy	10	10	11	10	10	10
Latvia	23	22	19	20	20	19
Lithuania	22	27	25	26	27	27
Luxembourg	12	12	9	13	13	12
Netherlands	6	6	6	8	7	7
Poland	26	26	21	27	25	26
Portugal	14	13	16	11	11	13
Romania	27	23	18	25	21	23
Slovakia	25	20	26	21	22	23
Slovenia	16	17	22	15	15	17
Spain	8	9	10	9	9	9
Sweden	1	1	1	1	1	1
Türkiye	21	25	27	22	24	25

Sweden, Finland, Germany, Denmark, and Austria are the top five countries in terms of renewable energy performance, per the 2020 BORDA statistics. With BORDA ranks ranging from 6 to 13, the upper-middle group comprises nations like Estonia, the Netherlands, Belgium, Spain, Italy, Greece, Portugal, and Luxembourg. These nations demonstrate consistent progress in diversifying their energy sources and enhancing the capacity of renewable energy. The Czechia, Slovenia, Bulgaria, Ireland, and France comprise the middle-performing group, which exhibits mediocre performance. Although these nations have made some strides in their renewable energy capabilities, they still face challenges with grid modernization, policy consistency, and reliance on traditional energy sources. Croatia, Cyprus, Latvia, Hungary, Slovakia, Poland, Romania, Lithuania, and Türkiye are all included in the low-performing group. This set of countries faces structural and institutional challenges that hinder the effective deployment of renewable energy technologies.

Table 6: Rankings of Counties by Different MCDM Methods, 2023

Countries	TOPSIS	CRADIS	GRA	COPRAS	ARAS	BORDA
Austria	5	6	6	4	5	5
Belgium	9	9	9	10	10	9
Bulgaria	18	15	13	18	14	14
Croatia	19	19	21	15	15	18
Cyprus	14	20	24	21	23	21
Czechia	24	21	17	22	21	22
Denmark	3	3	4	5	4	3
Estonia	11	5	5	3	3	6
Finland	2	2	1	2	2	2
France	20	14	14	17	13	14
Germany	7	7	8	7	7	7
Greece	8	10	10	11	12	10
Hungary	17	18	18	20	20	19
Ireland	15	17	15	16	17	16
Italy	16	16	20	13	16	17
Latvia	21	23	16	19	19	20
Lithuania	22	24	25	26	27	25
Luxembourg	12	13	11	14	18	13
Netherlands	4	4	3	6	6	4
Poland	25	22	22	23	22	23
Portugal	10	11	12	9	9	10
Romania	27	27	23	27	26	27
Slovakia	26	26	26	25	25	26
Slovenia	13	12	19	12	11	12
Spain	6	8	7	8	8	8
Sweden	1	1	2	1	1	1
Türkiye	23	25	27	24	24	24

Sweden, Finland, Denmark, the Netherlands, and Austria are the top five European countries in terms of renewable energy performance, according to the 2023 BORDA rankings. With the top ranking across all individual MCDM approaches, Sweden continues to hold its strong position. Estonia, Germany, Spain, Belgium, Greece, and Portugal are in the upper-middle performance category (BORDA ranks 6–10). Luxembourg, Slovenia, France, Bulgaria, Ireland, and Italy are among the middle-performing nations (BORDA ranks 12–17). In terms of renewable energy capacity and policy implementation, these nations demonstrate a moderate level of progress. Hungary, Croatia, Latvia, Cyprus, the Czechia, Poland, Türkiye, Slovakia, Lithuania, and Romania (BORDA positions 18–27) are represented in the lower performance tier. The spread of renewable energy in these nations is nevertheless hampered by institutional, financial, and infrastructure issues.

4.3. BORDA Results and Discussion: Country-Level Evaluation and Specific Cases

Table 7 presents the BORDA-integrated renewable energy performance rankings of European Union member states and Türkiye for the years 2015, 2020, and 2023.

Table 7: BORDA Ranking Results of Countries, 2015, 2020, 2023

	2015	2020	2023
Austria	5	5	5
Belgium	9	8	9
Bulgaria	14	18	14
Croatia	22	21	18
Cyprus	23	22	21
Czechia	11	16	22
Denmark	3	4	3
Estonia	7	6	6
Finland	2	2	2
France	18	15	14
Germany	4	3	7
Greece	10	11	10
Hungary	26	19	19
Ireland	17	14	16
Italy	6	10	17
Latvia	20	19	20
Lithuania	25	27	25
Luxembourg	13	12	13
Netherlands	19	7	4
Poland	24	26	23
Portugal	12	13	10
Romania	15	23	27
Slovakia	21	23	26
Slovenia	16	17	12
Spain	8	9	8
Sweden	1	1	1
Türkiye	27	25	24

The comparative analysis highlights the structural challenges faced by the Southern and Eastern areas, as well as the continued leadership of Northern European nations. The research that follows covers the top countries, France and the Netherlands' structural constraints, Türkiye's unique position, and other noteworthy country-specific trends that were noted during the study period.

4.3.1. The Leading Five Countries and the Drivers of Their Success

4.3.1.1. Sweden

In all three years, Sweden remained in the top spot, solidifying its status as Europe's clear leader in the switch to renewable energy. An early and thorough legislative framework that prioritized hydropower, wind energy, and bioenergy, together with an efficient carbon taxation system implemented in the early 1990s, is credited with the nation's success. Strong environmental governance and technological innovation support Sweden's energy model, which is distinguished by a high percentage of renewable energy sources in district heating and power generation (IEA, 2023; Lund et al., 2015). One of the most sophisticated low-carbon systems in the world has been established thanks to public support for sustainable energy and stable regulatory frameworks (OECD, 2021).

4.3.1.2. Finland

Due to its diverse renewable energy portfolio, which is primarily dominated by biomass and combined heat and power (CHP) systems, Finland has consistently ranked second over the analyzed period. The efficient use of bioenergy has been made possible by the nation's extensive forest resources and interconnected district heating networks. Finland's long-term plan to become carbon neutral by 2035 provides a solid basis for further advancements in energy efficiency and the integration of the circular economy (Ministry of Economic Affairs and Employment of Finland, 2022; Eurostat, 2023). Finland's consistent leadership has been strengthened by strong industry engagement, innovative incentives, and policy coherence (Korppoo and Korhonen, 2019).

4.3.1.3. Denmark

Denmark's leadership in wind energy technology and community-based renewable energy governance has kept it in the top three for all evaluation years. The Danish energy transition paradigm, which dates back to the 1980s, places a strong emphasis on municipal ownership, citizen engagement, and policy continuity. Wind now provides more than 40% of the nation's electricity, and its performance has been further improved by long-term carbon pricing and energy efficiency initiatives (DEA, 2023; Lund and Mathiesen, 2009). Denmark continues to set the standard for sustainable energy systems, thanks to its unique blend of decentralized governance, technological innovation, and public confidence.

4.3.1.4. Germany

The Energiewende, a comprehensive plan to increase energy efficiency and replace nuclear and fossil fuel-based electricity with renewables, is responsible for Germany's strong performance in 2015 and 2020. The nation has made significant strides in energy storage, system upgrades, and the expansion of solar and wind power. However, in 2023, Germany ranked seventh overall due to a minor decline brought on by rising transition and integration costs (Agora Energiewende, 2023; Haas et al., 2021). Germany continues to play a key role in European clean energy innovation and policymaking, despite these obstacles (BMWK, 2023).

4.3.1.5. Austria

Due to its energy mix, which is based on hydropower and provides around 70% of its total electricity, Austria has consistently ranked fifth in all three years. The nation benefits from its alpine terrain, robust environmental regulations, and well-coordinated regional energy plans (IEA, 2022). A robust energy infrastructure that strikes a balance between supply security and environmental sustainability is supported by Austria's emphasis on integrating energy storage, promoting sustainable transportation, and utilizing renewable heating (Kohlheb & Diendorfer, 2020).

4.3.2. France and the Netherlands: Structural Constraints Limiting Top-Tier Performance

4.3.2.1. France

Due mainly to its significant reliance on nuclear power, which, despite being low-carbon, restricts the proportionate contribution of renewables, France maintained its mid-tier rankings (18th in 2015, 15th in 2020, and 14th in 2023). The centralized electricity system and drawn-out administrative processes have also hampered the growth of renewable energy. Although deployment has been accelerated by recent frameworks like the Programmation pluriannuelle de l'énergie (PPE), implementation is still occurring gradually (IEA, 2023; Cour des Comptes, 2021). Therefore, France's energy transition is a careful balancing act between increasing the use of renewable energy sources and preserving energy independence through nuclear power.

4.3.2.2. The Netherlands

One of the most significant increases is shown in the Netherlands, which rose from 19th in 2015 to 7th in 2020 and 4th in 2023. However, its late adoption of renewable energy prohibited it from being included among the top performers sooner. Through massive offshore wind expansion, solar subsidies, and carbon pricing systems, the Netherlands, which has historically relied on natural gas and fossil fuel infrastructure, has recently expedited its transition (PBL Netherlands Environmental Assessment Agency, 2022). However, its full renewable potential is still hindered by high population density, inadequate grid adaptation, and limited land availability (IEA, 2022; Dutch Ministry of Economic Affairs and Climate Policy, 2023).

4.3.3. Türkiye's Position and Structural Challenges

Despite a slightly improving trend, Türkiye remains one of the worst-performing nations during the whole period (ranked 27th in 2015, 25th in 2020, and 24th in 2023). The enormous potential for renewable energy in the nation, particularly in solar, wind, and geothermal energy, has not yet yielded commensurate performance gains. Inadequate grid modernization, policy unpredictability, and structural reliance on imported fossil fuels continue to be significant obstacles (World Bank, 2022; IRENA, 2023). Although private investment has been encouraged by the Renewable Energy Support Mechanism (YEKDEM), its overall efficacy has been diminished by uneven regulatory implementation and a lack of technology integration (TÜREB, 2022). To meet EU-level transition criteria, Türkiye must prioritize policy stability, domestic manufacturing capacity, and full grid integration to enhance future performance (Karakaş, 2023).

4.3.4. Notable Country-Specific Developments

Beyond the top and bottom performers, several countries display distinctive developments:

- Estonia maintained a strong position (7th → 6th → 6th), supported by early diversification and a robust digital infrastructure that enabled efficient energy monitoring (Eurostat, 2023).
- Spain consistently ranked in the upper-middle range (8th → 9th → 8th), driven by robust solar and wind investment and favorable climatic conditions (IEA, 2023).

- Portugal progressed from 12th to 10th place, reflecting the successful phase-out of coal and liberalization of the renewable market (EIA, 2023).
- Slovenia improved from 16th to 12th, benefiting from small-scale solar projects and EU-funded efficiency initiatives (European Commission, 2023).
- Poland and Romania remained near the bottom due to coal dependency and the delayed implementation of EU directives (IEA, 2022).
- Lithuania and Slovakia occupy the lowest ranks, constrained by grid limitations, low investment capacity, and slow policy harmonization (Eurostat, 2023).

4.3.5. Overall Assessment and Discussion

The findings show that Europe's performance in renewable energy is consistently divided between the North and South as well as the West and East. Strong policy continuity, sophisticated infrastructure, and widespread public acceptance of renewable technology are still characteristics of Northern and Central European nations (Sweden, Finland, Denmark, Austria, and Germany). While Eastern and Southeastern Europe lag behind due to institutional and structural hurdles, Western Europe—represented by France, Belgium, and the Netherlands—exhibits consistent but uneven growth (European Commission, 2023; IEA, 2023).

The chronology of Türkiye reveals a period of transition, marked by great promise but limited systemic execution. Long-term regulatory coherence, innovation-driven industrial strategy, and investments in energy storage and smart grid technologies are all needed to make significant progress. All things considered, the BORDA-integrated results underscore the need for ongoing collaboration and policy harmonization to ensure a fair and equitable transition to renewable energy throughout Europe.

A study closely related to this research is that of Ozsoy et al. (2024), titled "Renewable Energy Preferences of European Countries and Türkiye: Use of Multi-Criteria Decision Making." While both studies employ MCDM techniques to examine renewable energy dynamics in European countries and Türkiye, their objectives and methodological scopes differ. Nakipoğlu Ozsoy et al. (2024) primarily focus on identifying countries' renewable energy preferences and policy orientations by comparing the years 2010 and 2020 through the PSI, WEDBA, and CODAS methods, emphasizing how resource intensity and national policies shape investment tendencies. In contrast, the present study evaluates the performance of 26 European countries and Türkiye over a longer period (2015–2023) by employing a comprehensive combination of objective weighting (CRITIC, LOPCOW, and Standard Deviation) and ranking methods (ARAS, COPRAS, CRADIS, GRA, and TOPSIS), integrated through the BORDA aggregation technique. Whereas Ozsoy et al. (2024) identify Germany as the leading country in renewable energy preferences; the current analysis confirms the leadership of Northern European countries such as Sweden, Finland, and Denmark in overall renewable energy performance. Both studies consistently underscore Türkiye's gradual improvement, despite structural and institutional challenges, highlighting the need for stable, long-term policies and regionally balanced energy transitions. In this respect, the findings of Ozsoy et al. (2024) complement the present research by providing a comparative framework for understanding how policy orientation and resource allocation evolve in tandem with measurable performance outcomes within the European renewable energy landscape.

4.4. Conclusion and Policy Implications

This study employed a multi-method evaluation framework integrated through the BORDA aggregation approach to analyze the renewable energy performance of European Union Member States and Türkiye for the years 2015, 2020, and 2023. The major nations—Sweden, Finland, Denmark, Germany, and Austria—showed a steady trend of performance stability, while Eastern and Southeastern European countries, notably Türkiye, continued to fall behind. The findings show that although Europe's transition to renewable energy has been generally successful, it remains uneven in space and institutionally fragmented, with each nation's path shaped by different levels of policy maturity, technological advancement, and sociopolitical engagement.

The steadfast leadership of Northern and Central European nations demonstrates that societal legitimacy, regulatory stability, and long-term policy coherence are crucial for a successful transition to renewable energy. Policy frameworks in these nations have been continuously refined through iterative learning processes since they were first established decades ago. High renewable penetration and the institutionalization of sustainability as an economic paradigm have been made possible by stable carbon pricing, community engagement models, and innovation-driven industrial strategies (IEA, 2023; European Commission, 2023).

Conversely, lower-performing and mid-tier nations, such as France, the Netherlands, and Türkiye, exhibit limited or transient trends. Path dependency in national energy systems can impede diversification even under aggressive climate targets, as seen by France's continued reliance on nuclear power, which suppresses the proportionate growth of renewables. A more dynamic example is the Netherlands, which has made significant strides in expanding offshore wind and reforming the carbon market, yet still faces infrastructure and geographic constraints. A developing but fragmented renewable sector, where significant resource potential coexists with inconsistent policies, insufficient grid modernization, and fossil fuel dependency, is reflected in Türkiye's slow improvement.

The comparison findings confirm the presence of a North–South and West–East split in renewable energy performance from a regional standpoint. Southern and Eastern Europe are still limited by institutional, financial, and regulatory constraints, whereas Northern and Western Europe exhibit technological innovation and policy maturity. This discrepancy highlights the need for greater policy harmonization at the EU level, particularly in areas such as cross-border energy trade, grid integration, and renewable energy funding.

4.4.1. Policy Implications

The findings of this study yield several key policy implications for national governments, regional institutions, and energy stakeholders:

1. Institutional Stability and Long-Term Policy Frameworks: Stable governance and continuity in energy policy are characteristics of the best-performing nations. In lagging nations, establishing legally binding, multi-decade renewable energy objectives backed by transparent monitoring systems can significantly enhance investor confidence and policy effectiveness.
2. Grid Modernization and Storage Integration: As the use of renewable energy sources increases, balancing erratic supply and demand becomes more challenging. To ensure system dependability and energy security, policies should prioritize investments in smart grids, digital monitoring systems, and large-scale storage options (Agora Energiewende, 2023).
3. Diversification of Energy Sources and Market Tools: Flexibility and resilience are compromised by an excessive reliance on a single resource, whether it be coal in Poland or nuclear in France. The shift can be accelerated without distorting competition by introducing

diversified renewable portfolios backed by market-based tools, such as feed-in prices, green certificates, or auction-based procurement.

4. Financial Mechanisms and Just Transition Strategies: To overcome capital limitations and policy fragmentation, Eastern and Southeastern European nations require targeted financial assistance. Regional green investment funds and the EU's Just Transition Mechanism should be expanded to promote equitable growth and help close current gaps (European Commission, 2023).
5. Public Participation and Local Governance: The examples of Austria and Denmark demonstrate how citizen cooperatives and community ownership models enhance legitimacy and accelerate the adoption of renewable energy. To achieve more egalitarian energy outcomes, policymakers in emerging markets should consider participatory frameworks that integrate social engagement with technological innovation.
6. Türkiye's Strategic Priorities: In particular, a cogent energy transition plan for Türkiye should incorporate grid upgrading, domestic production of renewable energy technology, and uniform application of the law. Economic competitiveness and environmental sustainability would both be improved by strengthening institutional coordination and aligning national targets with EU renewable energy requirements (World Bank, 2022; Karakaş, 2023).

4.4.2. Final Remarks

The BORDA-integrated results indicate that, although Europe's shift to renewable energy has reached a mature stage, regional differences in progress persist. In the future, policy convergence, financial solidarity, and adaptable governance mechanisms will be just as important as technology innovation for the European Green Deal and larger decarbonization goals. Continuous multi-criteria evaluation, such as the methodology used in this study, may be an essential tool for tracking performance, comparing the efficacy of policies, and informing data-driven decision-making in the pursuit of a resilient, carbon-neutral Europe.

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