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Assessment of Wind Power Plant Potentials via MCDM Methods in Marmara Region of Turkey

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Abstract

Today the use of renewable energy sources is increasing day by day. The essential advantages of the wind energy are that it is clean, of low cost, and unlimited. In this work, the wind energy potential of the provinces of the Marmara region in Turkey is evaluated by the multi-criteria decision-making (MCDM) methods. The TOPSIS and PROMETHEE methods are used for analysis of the criteria weights by two different approaches. In the first approach, the criteria weights are taken equally. In the second approach, the criteria are weighted using the AHP method. When the methods are applied by taking the criteria weights equally, Balıkesir and Çanakkale are determined as the wind priority provinces in potential, while Kocaeli and Sakarya take the last rank. After the criteria weights are determined via AHP when the TOPSIS and PROMETHEE methods are applied, Balıkesir ranks first and Kocaeli ranks last. The Spearman's correlation coefficient determines the level and direction of the relationship between the rankings obtained from the TOPSIS and PROMETHEE methods. When the methods are applied, the value of “0.636” indicate that the relationship between the rankings is “positive” and “moderate”. When the criteria are weighted with AHP, and the methods are applied, the correlation coefficient is obtained as “0.909”. This value indicates a “positive” and “very high” level of relationship. The ranking results obtained when the methods are applied after the criterion weights are calculated with AHP are more supportive of each other.

Keywords: *AHP, Renewable energy, TOPSIS, PROMETHEE, Wind energy, Wind power plant.*

1. Introduction

The energy resources are indispensable factors for a country's social welfare and economic development [1], [2]. One of the most critical energy components is electricity, which is one of the secondary energy sources. The electricity demand is increasing day by day with the use of technology [3]. Although the electrical energy is mainly obtained from the traditional energy sources such as coal and petroleum, the traditional resources are inadequate and have adverse environmental effects. For this reason, it is becoming widespread to obtain the electrical energy from renewable energy sources [4]. In the recent years, the wind energy has become one of the important renewable energy sources worldwide because it is known that the wind energy is clean, of low cost, and unlimited [5].

Nowadays, the wind energy is commonly used in order to produce electrical energy in numerous countries such as Germany, Spain, United States, India, and Denmark [6]. Turkey has the potential to meet the total energy requirements from the wind energy. The most suitable areas for the use of wind energy are the Marmara, Southeastern Anatolia, and Aegean regions in Turkey [7]. Besides, Turkey is one of the world's fastest-growing wind power energy markets. In 2020, Turkey rose to the fifth place in Europe in the wind energy production equipment. 44 countries on six continents are exporting for the wind power plant equipment [8].

The issues such as wind energy potential evaluation are decision environments where more than one criterion is evaluated. There are studies in the literature on the wind energy including the MCDM methods. Some of the studies in the literature are summarized below.

Elmahmouidi *et al*. [9] have aimed to determine the most appropriate areas for wind farms in Tarfaya (Morocco) using the Fuzzy-AHP and GIS methods. Supciller *et al*. [10] have proposed a decision model for the selection of wind turbines in Turkey. The criteria were weighted according to the SWARA method. The degrees of significance for the criteria were first given by the experts using neutrosophic numbers with linguistic variable definitions. The TOPSIS and EDAS methods were used as the integrated solution methods with monovalent neutrosophic numbers. Moradi *et al*. [11] have aimed to analyze a multi-criteria decision support system in orderto assess the wind energy in Iran. In their study, AHP and GIS were used, and finally, the effect of change in criterion weights was examined by the sensitivity analysis. Rehman *et al*. [12] have evaluated the selection of wind power plant locations in Saudi Arabia. They determined the most suitable plant location using the PROMETHEE method after entropy-based criterion weighting. Degirmenci *et al*. [4] have evaluated the wind energy projects using the GIS and AHP methods in Turkey.

In this work, the Turkey's wind power plant potential of the provinces in the Marmara region, one of the areas suitable for energy, was evaluated by the MCDM methods. It is aimed to make the wind energy potential ranking and selection on a provincial basis. Two approaches are presented for the criteria weights to be used in the TOPSIS and PROMETHEE method steps. In the first approach, the criteria weights were taken equally. In the second approach, the criteria were weighted using AHP, one of the MCDM methods. Evaluation of the provinces in the Marmara region was made using the TOPSIS and PROMETHEE methods via decision matrix for the provinces. The results obtained from the methods were compared using the Spearman's rank correlation coefficient.

2. Materials and method

The Marmara region is in NW Turkey. It is the economically and socially most developed region of Turkey, and has a population of 25 million. The Marmara region has an area of 72,845 km², and there are 11 provinces in this region. The Marmara region and the provinces in this region are shown in figure 1 [13].

In this work, the wind power plant potential of the provinces (Balıkesir, Bilecik, Bursa, Çanakkale, Edirne, İstanbul, Kırklareli, Kocaeli, Sakarya, Tekirdağ, Yalova) included in figure 1 was evaluated using the TOPSIS and PROMETHEE methods from the MCDM methods. The relationship between the province rankings obtained from the methods was obtained by calculating the Spearmans' correlation coefficient. The evaluation criteria in the decision problem are given in table 1 [14], [15].

The criteria in table 1 were weighted with two approaches, and the effect levels on the decision problem were determined. In the first approach, the weights of all criteria were taken equally, with a total weight of 1,000. In the second approach, the expert opinions were evaluated, and the criteria were compared with each other in pairs. The criteria were weighted via the AHP method.

The decision matrix is included in table 2.

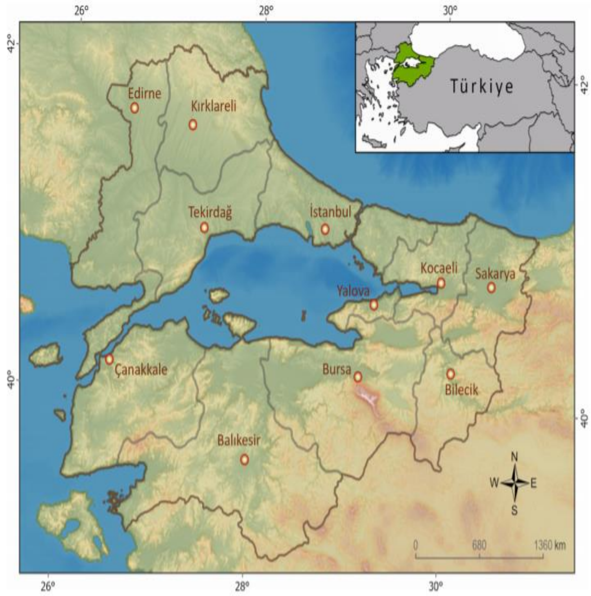

Figure 1. Map of Marmara region [13].

Table 1. Wind power plant potential evaluation criteria.

Wind power plant potential evaluation criteria	Units of criteria
C1. Theoretical potential power value	MW (megawatt)
C2. Installed power value of power plants taken into operation	MW (megawatt)
C3. Number of power plants commissioned	-
C4. Total transaction	MW (megawatt)
C5. Transaction-theoretical ratio	% (percent)
C6. Province annual average wind speed level	m/s category

The dataset to be used as a decision matrix in the TOPSIS and PROMETHEE methods is given in table 2.

2.1. TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method

The TOPSIS method is an MCDM method with a strong foundation, and is easy to understand, developed by Hwang and Yoon. The steps of the TOPSIS method are summarized below [16].

Step 1. Creation of decision matrix as in Table 3.

Table 2. Data matrix in this work.

Alternatives/Criteria	C1	C2	C3	C4	C5	C6
Balıkesir	13827	1181	30	1539	0.11	2
Çanakkale	13013	653	23	1328	0.1	8
Tekirdağ	4627	172	10	294	0.06	6
İstanbul	4177	326	20	930	0.22	4
Bursa	3882	133	6	373	0.1	3
Edirne	3470	172	5	540	0.16	3
Kırklareli	3079	243	6	494	0.16	4
Yalova	533	120	4	276	0.52	3
Kocaeli	334	10	1	94	0.28	3
Bilecik	309	60	3	160	0.52	3
Sakarya	180	10	2	180	1	2

Table 3. Decision matrix.

Weights of criteria	W_1	W_2	…	Wj
Criteria/Alternatives	a	b	c	…
f_1	fa1	fb1	fc1	…
f_2	fa2	fb2	fc2	…
…	…	…	…	…
…	…	…	…	…
fj	…	…	…	… fij
	fam	fbm	fcm	… fnm

Table 3 includes the criteria weights ($\mathbf{W_j}$) as well as the dataset for the criteria.

Step 2. Normalization of the decision matrix as equation 1.

$$r_{ij}=\frac{f_{ij}}{\sqrt{\sum_{i=1}^{m} f_{ij}^2}} \tag{1}$$

$$R=\begin{bmatrix} R_{11} & R_{21} & \cdots & R_{1M} \\ \vdots & & \ddots & \vdots \\ R_{1M} & R_{2M} & \cdots & R_{NM} \end{bmatrix}$$

Step 3. Calculation of the weighted normalized matrix. The weighted normalized decision matrix v_{ij} was calculated according to Eq. (2). The criteria weights ($\mathbf{W_j}$) could be taken equal or could be calculated using different MCDM methods such as AHP, SAW, and ANP.

$$V_{ij} = W_J R_{IJ} \tag{2}$$

Step 4. Determination of the positive ideal solution (A^*) and the negative ideal solution (A^-) as Eqs. (3) and (4), respectively. I shows the benefit (maximization) and I' the loss (minimization) criterion functions.

$$A^* = \left\{ (\max_I V_{IJ} \mid J \in I), (\min_I V_{IJ} \mid J \in I') \right\}$$
$$A^* = \{V_1^+, V_2^+, \ldots V_M^+\} \tag{3}$$

$$A^- = \left\{ (\min_I V_{IJ} \mid J \in I), (\max_I V_{IJ} \mid J \in I') \right\}$$
$$A^- = \{V_1^-, V_2^-, \ldots V_M^-\} \tag{4}$$

Step 5. Calculation of the distances from each alternative to the positive ideal solution and negative ideal solution as equations 5 and 6.

$$S_I^+ = \sqrt{\sum_{I=1}^{N} (V_{IJ} - V_I^+)^2} \tag{5}$$

$$S_I^- = \sqrt{\sum_{I=1}^{N} (V_{IJ} - V_I^-)^2} \tag{6}$$

Step 6. Calculation of the relative closeness to the ideal solution for each alternative as equation 7. Ranking of alternatives from the best to the worst according to the decrease in these values.

$$RC_I = \frac{S_I^-}{S_I^- + S_I^+} \tag{7}$$

2.2. PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) method

The PROMETHEE method is one of the MCDM methods developed by Brans *et al*. It is a valuable ranking method in design and implementation [17]. The steps of the PROMETHEE method are summarized below:

Step 1. Creating the decision matrix as in table 3.

Step 2. Defining the preference functions for each criterion. The preference functions are given in table 4.

Step 3. Calculation of the preference indices as equation 8.

$$\Pi(A,B) = \frac{\sum_{J=1}^{J} W_J P_J(A,B)}{\sum_{J=1}^{J} W_J} \tag{8}$$

Step 4. Computing the partial sequences of alternatives by calculating the transition flow with PROMETHEE I as equations 9, 10 and 11, respectively.

$$\phi^+(A) = \sum_A \Pi(A,B) \tag{9}$$

$$\phi^-(A) = \sum_A \Pi(B,A) \tag{10}$$

$$\phi(A) = \phi^{+}(A) - \phi^{-}(A) \quad (11)$$

Step 5. Achieving full ranking with PROMETHEE II. If (a) > $\phi(b)$, alternative a has priority; otherwise, alternative b prevails. If (a) = $\phi(b)$, the alternatives a and b are not superior to each other.

Table 4. Preference functions.

Type of preference functions	Definition of function	Parameter
Type I (Classic)	$p(d) = \begin{cases} 0 d \leq 0 \\ 1 d > 0 \end{cases}$	-
Type II (U Type)	$p(d) = \begin{cases} 0 d \leq q \\ 1 d > q \end{cases}$	q
Type III (V Type)	$p(d) = \begin{cases} 0 d \leq 0 \\ \frac{d}{p} 0 < d \leq p \\ 1 d > p \end{cases}$	p,q
Type IV (Level)	$p(d) = \begin{cases} 0 d \leq 0 \\ \frac{1}{2} 0 < d \leq p \\ 1 d > p \end{cases}$	p,q
Type V (Linear)	$p(d) = \begin{cases} 0 d \leq q \\ \frac{1}{2} 0 < d \leq p \\ 1 d > p \end{cases}$	p,q
Type VI (Gaussian)	$p(d) = \begin{cases} 0 d \leq 0 \\ 1 - e^{\frac{-d^2}{2s^2}} > q \end{cases}$	s

2.3. AHP (Analytic Hierarchy Process) method

AHP is an MCDM method proposed by Saaty [18]. AHP is a method that evaluates a finite number of criteria in a decision problem, and ranks them according to their importance [19].

The steps of the AHP method are summarized below:

Step 1. Create a hierarchical structure for the decision problem. The criteria for the purpose are determined.

Step 2. Preparation of the pairwise comparison matrix. The criteria (n) in the decision problem are compared with each other in pairs. The pairwise comparison matrix (A) is a nxn matrix.

The matrix structure is given in equation 12. The priority for each criterion is defined by the expert opinions according to its contribution to the goal. The basic scale is given in table 5.

$$A = \begin{bmatrix} 1 & \cdots & A_{N1} \\ \vdots & 1 & \vdots \\ 1/A_{N1} & \cdots & 1 \end{bmatrix}_{NXN} \quad (12)$$

Table 5. Fundamental scale in AHP [20].

Scale	Implication
1	Importance of the two criteria is the same
3	A criterion is moderately important than other criteria
5	A criterion is strongly important than other criteria
7	A criterion is demonstrated importance than other criteria
9	A criterion is extremely important than other criteria
2,4,6,8	Intermediate value

Step 3. Normalizing the comparison matrix and calculating the priority vector. For each column in the pairwise comparison matrix, the matrix is normalized by taking the column sums and dividing the elements in the matrix by the corresponding column sum. Then the row sums are taken for each criterion in the normalized matrix. The calculated values are the priority values for the criteria, and the matrix formed by these values is the priority matrix. The eigenvector shows the priority of each criterion among the other criteria in the matrix.

Step 4. Elements in the priority matrix created with the priority vector are multiplied by the elements in the pairwise comparison matrix. The weighted total matrix is obtained. The "λ_{max}" value is calculated by taking the arithmetic average of the values of the last matrix in the ($nx1$) dimension, which is formed by dividing the total row values in the weighted total matrix by the obtained priority matrix row values.

Step 5. Calculation of consistency index (CI) and consistency ratio (CR). Whether the interaction determined in the paired comparisons is consistent or not is measured by calculating CR. The formula for CI is given in equation 13.

$$CI = \frac{\Lambda_{MAX} - N}{N - 1} \quad (13)$$

The random consistency index should be given to evaluate the consistency, as shown in table 6.

The formula for CR is given in equation 14.

$$CR = \frac{CI}{RI} \quad (14)$$

If CR is less than 0.10, the decision is that the matrix is consistent.

Table 6. RI values for matrix [21].

n (number of criteria)	RI
1	0.00
2	0.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49
11	1.51
12	1.54
13	1.56
14	1.57
15	1.59

2.4. Spearman's rank correlation coefficient

The Spearman's rank correlation coefficient is specified as r_s for a sample statistic. The formula for calculating r_s for a correlation between the x and y variables is given in equation 14 [22].

$$R_S = 1 - \frac{6\sum_{I=1}^{M} D_I^2}{M(M^2-1)} \quad (14)$$

where d_i is the difference in ranks for x and y, and m is the number of alternatives. Table 7 contains the linguistic expressions of the correlation degrees for the correlation coefficients.

Table 7. Linguistic expressions for size of Spearman's rank correlation coefficient [23].

Size of correlation	Linguistic expressions
0.90 to 1.00	Very higy (+ or -)
0.70 to 0.90	High (+ or -)
0.50 to 0.70	Moderate (+ or -)
0.30 to 0.50	Low (+ or -)
0.00 to 0.30	Negligible (+ or -)
+: Positive correlation -: Negative correlation	

3. Results and discussion

After determining the alternatives and the criteria, the decision matrix was created. The wind power plant potential rankings of the provinces in the Marmara region were obtained. The criteria weights required for the TOPSIS and PROMETHEE method steps were obtained with two different approaches. In the first approach, the weights of all criteria tabulated in table 1 were taken equal, with a total weight of 1.000. The weight of each criterion was determined as "0.167". In the second approach, the criteria were weighted using the AHP method using the expert opinions. The pairwise comparison matrix for the criteria and the criteria weights obtained are given in table 8. CR was calculated as "0.093". Since this value is less than 0.10, the comparison matrix is consistent.

Table 8. Criteria weights obtained via AHP.

Criteria	C1	C2	C3	C4	C5	C6	Weights
C1	1	1/2	1/3	1	2	4	0.148
C2	2	1	3	2	3	3	0.303
C3	3	1/3	1	5	3	3	0.274
C4	1	1/2	1/5	1	2	2	0.123
C5	1/2	1/3	1/3	1/2	1	3	0.094
C6	1/4	1/3	1/3	1/2	1/3	1	0.058

The rankings obtained by the TOPSIS and PROMETHEE methods are given in table 9.

According to the rankings obtained from the methods, in the first approach, Balıkesir and Çanakkale were important provinces in the wind energy and power plant potential. Kocaeli and Sakarya were determined as the last provinces of ranks. In the second approach, the criteria weights were determined with AHP. According to results obtained from the TOPSIS and PROMETHEE methods, Balıkesir ranked first, and Kocaeli ranked last. The r_s value determines the degree and direction of the relationship between the rankings obtained from the methods. In the first approach, the Spearman's correlation coefficient between the two rankings from the methods was calculated as r_s = 0.636. Since this value was between the values of 0.50 and 0.70 and it was a positive value, the relationship between the rankings obtained from the two methods was "moderate" and "positive". In the second approach, r_s was calculated as "0.909". Since this value was between the values of 0.90 and 1.00 and it was a positive value, the relationship between the rankings obtained from the two methods was "very high" and "positive".

Table 9. Ranking obtained from MCDM methods.

Provinces (alternatives)	First approach		Second approach	
	Ranking obtained from TOPSIS method	Ranking obtained from PROMETHEE method	Ranking obtained from TOPSIS method	Ranking obtained from PROMETHEE method
Balıkesir	1	2	1	1
Çanakkale	2	1	2	2
Tekirdağ	5	4	4	4
İstanbul	3	3	3	3
Bursa	10	7	8	7
Edirne	9	6	7	6
Kırklareli	7	5	5	5
Yalova	6	8	9	8
Kocaeli	11	10	11	11
Bilecik	8	9	10	9
Sakarya	4	11	6	10

First approach: Determination of criterion weights equally
Second approach: Determination of criterion weights with AHP

4. Conclusions

In this work, the wind power plant evaluation was made for the provinces in the Marmara region in Turkey, a suitable region for wind energy. The rankings of the provinces were obtained. For this purpose, the data of the provinces was analyzed using the TOPSIS and PROMETHEE methods, which are among the MCDM methods. The relationships between the results obtained from the methods that serve the same purpose but have different application steps. This relationship was positive. This situation supported the alternative possibilities of the methods.

As a result, in this work, in which the province-based evaluation of wind power plant potentials was examined with multi-criteria decision-making approaches, it was concluded that different methods could be used for the same purpose. This situation was confirmed via the Spearman's rank correlation coefficient obtained. In this context, they were using AHP while weighting the criteria in order to produce closer rankings from the MCDM methods. This work can contribute to future studies in terms of the method analysis and using alternative methods.

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6. References

[1] Takan M.A. and Kandemir S.Y. (2020). Evaluation of geothermal energy in Turkey in terms of primary energy supply. European Journal of Science and Technology, Special issue, pp. 381-385.

[2] Kandemir S.Y. (2016). "Assessment of coal deposit using multivariate statistical analysis techniques. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, Vol. 38, No. 7, pp. 1002-1006.

[3] Guler E., Kandemir S.Y., and Acikkalp E. (2020). Evaluation of the efficiencies of the energy distribution companies in Turkey with DEA. Bilecik Seyh Edebali University Journal of Science, Vol. 7, No. 1, pp. 66-79.

[4] Degirmenci S., Bingol F., and Sofuoglu, S.C. (2018). MCDM analysis of wind energy in Turkey: decision making based on environmental impact. Environmental Science and Pollution Research, Vol. 25, No. 20, pp. 19753-19766.

[5] Taner T. (2018). Economic analysis of a wind power plant: A case study for the Cappadocia region. Journal of Mechanical Science and Technology, Vol. 32, No. 3, pp. 1379-1389.

[6] Gokcek M., Bayulken A., and Bekdemir, S. (2007). Investigation of wind characteristics and wind energy potential in Kirklareli, Turkey. Renewable Energy, Vol. 32, No.10, pp. 1739-1752.

[7] Aras H. (2003). Wind energy status and its assessment in Turkey. Renewable Energy, Vol. 28, No. 14, pp. 2213-2220.

[8] Türkiye, Rüzgâr Enerjisinde Dünyanın En Büyük 10 Ülkesinden Biri, (2020), Available: https://temizenerji.org/2020/12/31/

[9] Elmahmoudi F et al. (2020). GIS based Fuzzy Analytic Hierarchy Process for wind energy sites selection in Tarfaya Morocco. In 2020 IEEE International conference of Moroccan Geomatics (Morgeo) pp. 1-5. IEEE.

[10] Supciller A.A. and Toprak, F. (2020). Selection of wind turbines with multi-criteria decision-making techniques involving neutrosophic numbers: A case from Turkey. Energy, Vol. 207, 118237.

[11] Moradi S. et al. (2020). Multi-criteria decision support system for wind farm site selection and sensitivity analysis: Case study of Alborz Province, Iran. Energy Strategy Reviews, Vol. 29, pp. 1-17.

[12] Rehman A.U. et al. (2019). Multi-criteria decision-making approach for selecting wind energy power plant locations. Sustainability, Vol. 11, No. 21.

[13] Coban V., Guler E., Kilic T., and Kandemir S.Y. (2021). Precipitation forecasting in Marmara region of Turkey. Arabian Journal of Geosciences, Vol 14, No. 2, pp. 1-10.

[14] Türkiye Rüzgar Enerjisi Potansiyeli Haritası, (2021), Available: https://www.enerjiatlasi.com/ruzgar-enerjisi-haritasi/turkiye

[15] Orman ve Su İşleri Bakanlığı Meteoroloji Genel Müdürlüğü, (2021), Available: http://www1.mgm.gov.tr/FILES/resmi-istatistikler/Turkiye-Ortalama-Ruzgar.pdf

[16] Chakraborty S. and Chatterjee P. (2017). A developed meta-model for selection of cotton fabrics using design of experiments and TOPSIS method. Journal of the Institution of Engineers (India) Series E, Vol. 98, No. 2, pp. 79-90.

[17] Albadvi A., Chaharsooghi S.K., and Esfahanipour A. (2007). Decision-making in stock trading: An application of PROMETHEE. European Journal of Operational Research, Vol. 177, No. 2, pp. 673-683.

[18] Saaty T.L. (1980). The Analytic Hierarchy Process, McGraw-Hill, New York.

[19] Aktepe A. and Ersoz S. (2014). AHP-VIKOR ve MOORA yöntemlerinin depo yeri seçim probleminde uygulanması. Journal of Industrial Engineering, Vol. 25, No.1, pp. 2-15.

[20] Teker S.C. (2017). The implementation of analytic hierarchy process in pharmaceutical industry for selection process of 3rd party logistics service provider. Oneri Journal, Vol.12, No.48, pp. 107-124.

[21] Saaty T.L. and Tran L.T. (2007). On The Invalidity of Fuzzifying Numerical Judgments in the

Analytic Hierarchy Process. Mathematical and Computer Modelling, Vol. 46, No. 7-8, pp. 962- 975.

[22] Mukaka M. (2012). Statistics corner: A guide to appropriate use of correlation in medical research. Malawi Med. J., Vol 24, No. 3, pp. 69-71.

[23] Guler E., Kandemir S.Y., Acikkalp E., and Ahmadi M.H. (2021). Evaluation of sustainable energy performance for OECD countries. Energy Sources, Part B: Economics, Planning, and Policy, 1-24.