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استخدام التحليل المبني على عوامل متعددة لتقييم أداء محطات انتاج الطاقة من الرياح

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خلاصة

تقدم هذه الدراسة تحليل القرار متعدد المعايير (mcda) لتقييم بدائل انتاج طاقة الرياح التي تقع في منطقة مرمره في تركيا. الهدف الرئيسي من هذه الدراسة هو إدراج معايير تحديد الأولويات لتقييم مختلف محطات طاقة الرياح. لتحقيق هذا الهدف تم اعتماد نموذج القرار الهرمي المبني على عوامل متعددة لاتخاذ القرار باستخدام نهج عمليات تحليل هرمي ضبابي (FAHP). تم استخدام التحكيم الكمي للخبراء وتم تقييم كافة البدائل وفق معايير اقتصادية وتقنية وبيئية. في الطريقة المقترحة تم اعطاء وزن لكل من عوامل التقييم عن طريق تحليل أداء المصفوفات (AHP). وأخيرا تم اختيار أفضل مجموعة إنتاج طاقة من الريح في المنطقة التي تم دراستها.

Use of multicriteria decision analysis to assess alternative wind power plants

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ABSTRACT

This study presents a multi-criteria decision analysis (MCDA) to evaluate the wind energy production alternatives located in Marmara region of Turkey. The main objective of the study is to incorporate the prioritization criteria for the assessment of various wind power plants. To achieve this aim, a hierarchical decision model based on multi-criteria decision making approach using Fuzzy Analytical Hierarchy Process (FAHP) is utilized, expert judgments are quantified, and the alternatives are evaluated with respect to the economic, technical and environmental criteria. In the proposed methodology, the weights of the selection criteria are identified by pairwise comparison matrices of AHP. From the performed analysis, the best wind production farm among the alternatives for establishing wind turbines in the considered region is determined.

Keywords: Fuzzy analytical hierarchy process; multicriteria decision analysis; wind power.

INTRODUCTION

There is no doubt that the move toward generating electricity from renewable resources has become the main trend in recent years. Renewable energy sources have been important for humans since the beginning of civilization. They are commonly accepted as the key for the future life because renewable energy sources have some advantages such as environmental improvement, increased fuel diversity, reduction of energy price volatility effects on the economy, national economic security and increase in economic productivity (Kaya & Kahraman, 2010). Interest in the use of renewable energy sources has grown dramatically during the last decade, largely as a reaction to concerns about the environment impact of the use of fossil and nuclear fuel. Because of the increasing negative effects of fossil fuels on environment, many countries have started to use renewable energy sources. With the recent increase in environmental awareness and macro trends such as global warming, the environmental impact of energy production processes has become a major concern in drafting of environmental policies. In the world, particularly in the developing countries like Turkey, renewable energy sources appear to be one of the most efficient and effective solutions for sustainable energy development. Turkey's geographical location has several advantages for extensive use of most of the renewable energy sources. Despite having rich potential for renewable energy, Turkey has so far only utilized a very small part of them. So, the energy demand will be met by fossil-based energy sources, even in the long term (Camdan, 2011; Ilkilic & Nursoy, 2010). Potential and current status of renewable energy in Turkey by the end of 2009 is given in Table 1.

Table 1. Potential and current situation of renewable energy sources in Turkey (Camdan, 2011)

Type of energy	Technical potential (MW)	Economical potential (MW)	Installed capacity (MW)
Hydropower	54.000	42.000	14.5
Wind	80.000	20.000	802.8
Geothermal	1.500	600	77.2
Wastes (biogas + biomass)	---	---	81.2
Solar	56.000	---	---

Among the renewable energy sources, wind energy being socially, beneficial, economically, competitive, and environmentally friendly has become the world's fastest growing and common using renewable energy source for electricity generation. Turkey is one of the windiest places in Europe and Asia; and can reduce its dependence on fossil fuels very quickly when using its domestic renewable potentials, and at very low costs, much lower than when continuing the fossil or nuclear approach (Kahraman *et al.*, 2009). Although Turkey has much higher technical wind power potential than other European countries, only a very small percentage of this potential is used. Total wind power installed in Turkey, wind energy generating capacity, was 371.65 MW at the end of 2008. Up to the end of 2009, 26 wind farms have been built in the main land with a total installed capacity of 713.45 MW. In 2010, 528 MW of new wind energy capacity was added in Turkey, bringing the total up to 1329 MW. Installed wind capacity is expected to grow at between 500 and 1000 MW per year reaching more than 12 GW by 2015. It is expected that by the year 2020, the renewable energy production will be 19,841.49 ktoe (kilo tonnes of oil equivalent), while renewable energy consumption will be 19,841.49 ktoe (Camdan, 2011). Turkey hopes to install up to 20 GW by 2023, helping the country to source 30% of its electricity generation from renewable sources by that date. Energy planning using multi-criteria analysis has attracted the attention of decision makers for a long time. In this paper, a hierarchical decision making approach based on multi-criteria decision making framework according to the criteria such as economic, technical, and environmental attributes is presented to prioritize the wind energy production farms. Each criterion is divided into several sub-criteria. The decision making process is applied using an analytical hierarchy process to help decision makers and private investors in determining the most suitable wind production farm in four regions of Turkey, namely, Corlu, Tekirdag, Edirne, and Krklareli, located in Marmara region of Turkey. For this aim, the opinions of decision makers on the relative importance of the selection criteria are determined by a fuzzy analytic hierarchy process since it is based on pairwise comparisons and allows the utilization of linguistic variables. This paper is set out as follows: a literature review on multi-criteria wind energy decision making approach is briefly presented in Section 2. The outline of the proposed approaches is described in Section 3.The results of FAHP approach associated with the selection of wind production site alternatives are given in Section 4. Concluding remarks are discussed in Section 5.

LITERATURE REVIEW

In the literature, the most used multi-criteria decision making methods for renewable energy investments are counted AHP, Analytic Network Process (ANP), Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE), a hybrid of Elimination Et Choix Traduisant la Realite'(ELECTRE) III, PROMETHEE II, and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). Several studies (Cavallarao & Ciraolo, 2005; Zangeneh, 2009; Lee *et al.*, 2012) have applied AHP for renewable energy planning. Pohekar and Ramachandran (2004) analyzed several methods based on weighted averages, priority setting, outranking, fuzzy principles and their combinations and employed for energy planning decisions. Opricovic and Tzeng (2004) conducted a comparative analysis of VIsekriterijumsko KOmpromisno Rangiranje (VIKOR) and TOPSIS methods with a numerical example. Chu *et al.*, (2007) provided a comparative analysis of SAW (Simple Additive Weighting), TOPSIS and VIKOR, which demonstrated the similarities and differences of these methodologies in achieving group decisions. Tzeng (2005) made a comparison of VIKOR with PROMETHEE, ELECTRE and TOPSIS approaches. Goletsis *et al.*, (2003) presented group techniques with multicriteria methods in an integrated methodology so as the prioritization of project proposals in the energy sector of Armenia. They developed a multicriteria ranking method, a hybrid of ELECTRE- III and PROMETHEE methods, and constituted the main part of an integrated project ranking methodology for groups. Haralambopoulos and Polatidis(2003) described an applicable group decision-making framework for assisting with multicriteria analysis in renewable energy projects, utilizing the PROMETHEE II outranking method to achieve group consensus in renewable energy projects. Beccali *et al.*, (2003) made an application of the multicriteria decision-making methodology to assess an action plan for the diffusion of renewable energy technologies at regional scale. They used ELECTRE-III method under fuzzy environment. Borges and Antunes (2003) presented an interactive approach to deal with fuzzy multiple objective linear programming problems based on the analysis of the decomposition of the parametric (weight) diagram into indifference regions corresponding to basic efficient solutions. Mavrotas *et al.*, (1999) proposed an approach based on a mixed 0-1 multiple objective linear programming (MOLP) model and applied to the Greek electricity generation sector to identify the number and output of each type of power units needed to satisfy the expected electricity demand in the future. Kaya and Kahraman

(2010) aimed at determining the best renewable energy alternative for Istanbul by using an integrated VIKOR-AHP methodology. Kahraman *et al*., (2009) used axiomatic design (AD) and AHP for the selection of the best renewable energy alternative under fuzzy environment. Önüt *et al*., (2008) employed analytic network process (ANP) to solve an energy resource selection problem for the manufacturing industry. In references (Damousis & Dokopoulos, 2001; Kahraman *et al*., 2009) a fuzzy model has been suggested for the prediction of wind speed and the produced electrical power at a wind park. However, the potential sites of wind generation of the country have not been completely investigated in detail yet. In the wind energy literature, many relevant works have been developed for this aim. Kim and Lee (1999) proposed a time-series prediction method using a fuzzy rule-based system. In order to solve the fuzzy logic drawback in non-stationary systems, they proposed a method of building fuzzy rules for prediction which utilized the difference of consecutive values in a time series. Damousis and Dokopoulos (2001) proposed a new methodological framework of multi-criteria decision making approach to evaluate renewable energy options in Greece. Zangeneh *et al*. (2009) presented an assessment and evaluation model for the prioritization of distributed generation technologies, both conventional and renewable energy source. For this aim, a multi-attribute decision making approach was used to assess the alternatives. Cavallaro and Ciraolo (2005) used Fuzzy-TOPSIS approach for assessing thermal-energy storage in concentrated solar power systems. They also proposed a multi-criteria method in order to support the selection and evaluation of one or more of the solutions to make a preliminary assessment regarding the feasibility of installing some wind energy turbines in a site on the island of Salina in Italy. Lee *et al*. (2012) constructed a comprehensive evaluation model, which incorporates interpretive structural modeling and fuzzy analytic network process, to select suitable turbines when developing a wind farm in Taiwan. In the literature, there are limited number of publications using FAHP to forecast the wind energy production. Except for Kaya and Kahraman (2010) and Zangeneh (2009), there is no research which present an assessment for the prioritization of the wind energy generation farms. In order to fill the vacancy in the literature, the paper will develop a selection model to help the evaluation of the wind farm projects.

METHODOLOGY

The multi-attribute decision making approach is one of the most suitable technical aids for strategic planning. Decision making techniques include various methods such as Analytical Hierarchy Process, which uses pairwise comparisons to assess decision makers' preferences; outranking methodologies such as PROMETHEE, ELECTRE, TOPSIS, and social multi-criteria evaluation (SMCE) techniques such as Novel Approach for Imprecise Assessment and Decision Evaluations (NAIADE). In addition, VIKOR is a multi-attribute decision making technique which has a simple computational procedure that allows simultaneous consideration of the closeness to ideal and anti-ideal alternatives. MCDM methods based on weighted averages, priority setting, outranking, fuzzy principles, and their combinations are employed for energy planning decisions. It is observed that AHP is the most popular MCDM technique followed by outranking techniques PROMETHEE and ELECTRE. The AHP enables the decision makers to structure a complex problem in the form of a simple hierarchy and to evaluate a large number of quantitative and qualitative factors in a systematic manner under multiple criteria environment in confliction. AHP approach shows the process of determining the priority of a set of criteria and the relative importance of a multi criteria decision making problem. It is widely used in the literature for solving a wide variety of problems that involve complex criteria across different levels (Tegou *et al.*, 2012). AHP has been developed under fuzzy conditions by various researchers (Pohekar & Ramachandran, 2004; Wang *et al.*, 2010; Polatidis *et al.*, 2006). The fuzzy set theory can address imprecision in the data presented in the AHP, as well as offer a more linguistic interpretation of the preference judgements made. Several fuzzy AHP approaches were applied to some industrial problems by researchers (Lee *et al.,* 2012). In this study, the proposed strategy is a hierarchical decision making structure that uses AHP to prioritize preferences for wind production farms according to various criteria such as economic, technical, and environmental. The general process of the fuzzy multi-criteria decision making model performed is shown in Figure 1. Members of this expert group were mostly selected among from academicians, as this study was an academic exercise. One electrical, one energy and two mechanical engineers, who have expertise in nuclear, renewable, especially wind energy production processes, were invited in order to make contributions to the evaluation of technical properties. An environmental engineer provided the evaluation of environmental factors, and another environmental engineer, who has background in environmental economics, contributed to assessment of emission trades. Beside this, two economists, who have expertise in energy economics, shared their opinions about economic factors. A meeting was organized in which all of the invited experts participated. All of the experts shared their knowledge with each other by discussing on each factor, and they gave a common score for each comparison instead of giving a score themselves. As a result, a holistic approach was provided by bringing different kinds of experts together in order to have a common conclusion for comparison of factors.

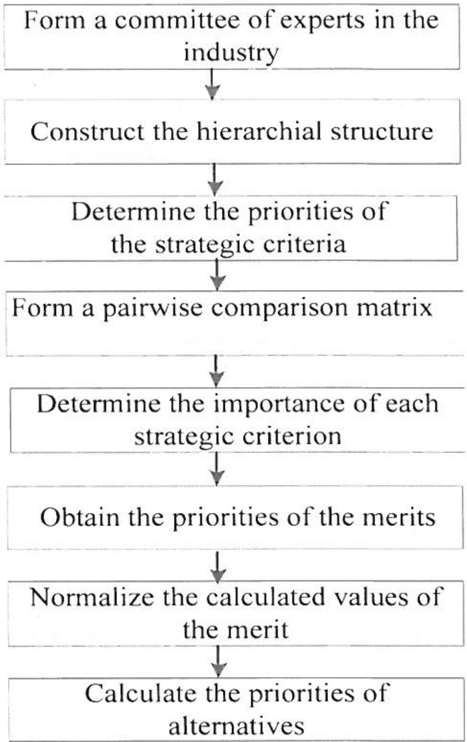

Fig. 1. The proposed fuzzy multi-criteria decision making process

Based on literature reviews and practical experiences, the evaluation committee considered the criteria shown in Table 2 as the most important factors for wind farm project, and these criteria will be used to select the best wind farm project in the subsequent real case study.

Table 2. The criteria and sub-criteria for wind farm project

Alternatives	Main-criteria	Sub-criteria
Tekirdag		
	Economic	Investment cost Operating cost Potential to electricity market
Corlu		
	Environmental	Risk Impact Emission
Edirne		
	Technical	Capacity
Kırklareli		Lifetime
		Efficiency

In this study, all elements have been defined and scored by an expert group using proposed fuzzy scale as shown in Table 3.

Table. 3. Fuzzy evaluation scores for the weights

Intensity of relative importance	Definition
1	Equal important
3	Moderately preferred
5	Essentially preferred
7	Very strongly preferred
9	Extremly preferred
2,4,6,8	Intermediate importance

A triangle fuzzy number scale is required to make a series of pairwise comparison among both main factors and sub factors. The linguistic variables used to make the pairwise comparisons are those associated with the standard 9-unit scale. The importance weights of factors are produced and priority values with realistic numbers are obtained using Fuzzy AHP model. The geometric mean method as the most widely applied method in AHP is used for the aggregation, as recommended by Saaty (1980). Suppose there are N expert respondents. The individual judgments of them are combined using Equation (1).

$$a_{ij} = \left(\prod_{k=1}^{N} a_{ij}^{k}\right)^{1/N} \tag{1}$$

where a_{ij}^{k} is the judgment of the kth voter when comparing item i with item j.

It is important to note that the efficiency of an AHP greatly depends on the accuracy of the pairwise weights. If there are n attributes in a level, then the squared matrix of attributes with respect to a higher attribute or goal will be presented as Equation (1).

$$A = \begin{bmatrix} a_1 & a_{12} & \dots & a_{1n} \\ 1/a_{12} & 1 & \dots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \dots & 1 \end{bmatrix}$$

where a_{ij} denotes the importance of ith attribute with respect to j th attribute. Aslo, it is assumed that $a_{ii} = 1$ and $a_{ij} = \frac{1}{a_{ij}}$.

The evaluation and final prioritization of wind energy production farms was accomplished with the aid of the AHP software, Expert Choice. The solution procedure of the fuzzy AHP approach involves six essential steps as follows:

Step 1. Define the problem and state clearly the objectives and results.

Step 2. Decompose the complex problem into a hierarchical structure with decision elements (criteria and alternatives).

Step 3. Employ pair-wise comparisons among decision elements and form comparison matrices with fuzzy numbers.

Step 4. Use the extent analysis method to estimate the relative weights of the decision elements (The defuzzification process is carried out here).

Step 5. Check the consistency of matrices to ensure that the judgments of decision makers are consistent.

Step 6. Aggregate the relative weights of decision elements to obtain an overall rating for the alternatives.

WIND ENERGY PLANNIG FOR THE CONSIDERED REGIONS

Energy planning using multi-criteria analysis has attracted the attention of decision makers for a long time (Cavallaro & Ciraolo, 2005; Damousis & Dokopoulos, 2001). Analytical hierarchy process, one of the most outstanding multicriteria decision- making approaches, has been used to solve energy problems successfully, and to help decision makers and private investors. The decision making process was applied in determining the most suitable wind production farm for four regions of Turkey, namely Tekirdag, Corlu, Edirne, Krklareli, located in Marmara region of Turkey. The map and location of the considered wind energy production sites are presented in Figure 2.

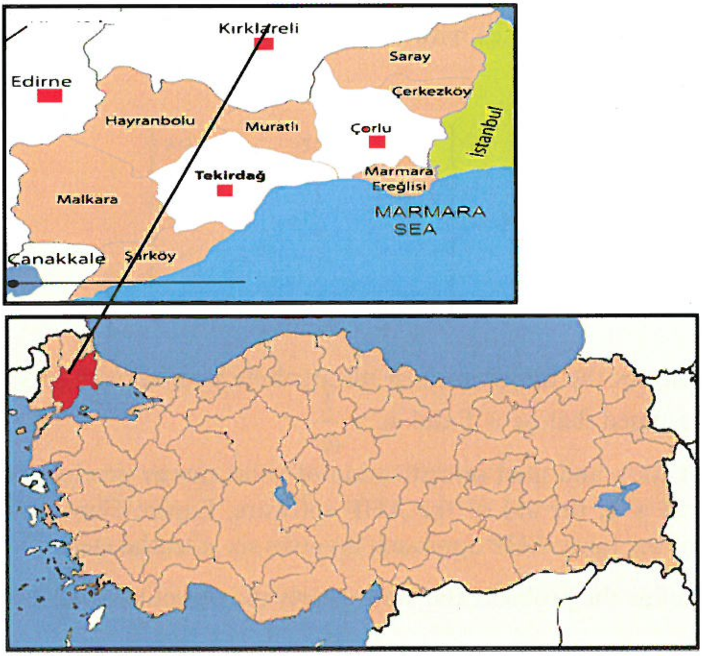

Fig.2. The location of the considered wind energy production sites

In this paper, a hierarchical decision making approach based on multi-criteria decision making framework according to the criteria such as economic, technical, and environmental attributes was presented to prioritize the wind energy production farms. For this aim, a combination of the most frequently used evaluation criteria in the literature was performed. Each criterion was divided into several sub-criteria. In the proposed approach, the opinions of decision makers on the relative importance of the selection criteria were determined by a fuzzy analytic hierarchy process since it is based on pairwise comparisons and allows the utilization of linguistic variables. The two level hierarchy composed of 3 main criteria and 9 sub-criteria and 4 alternatives were considered. The comparisons of priorities to each criterion are shown in Figure 3.

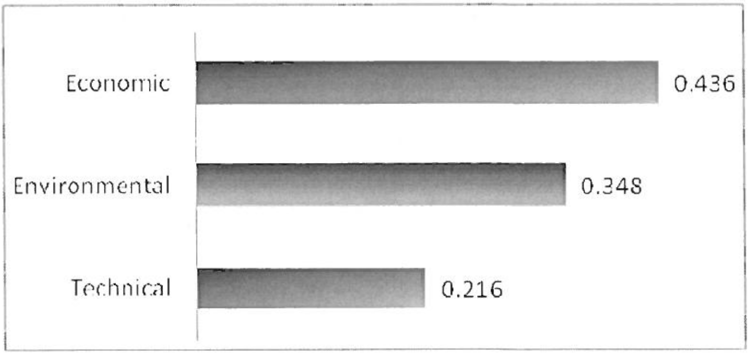

Fig. 3. Priority numbers of the main factors for selection the wind production farm

Among the main criteria, the most important criterion is potential, with a very high benepriority of 0.436. Nevertheless, the priority number of environmental criteria (0.348) is almost as high a technical criteria (0.216). The priority numbers of sub-criteria are shown in Figure 4.

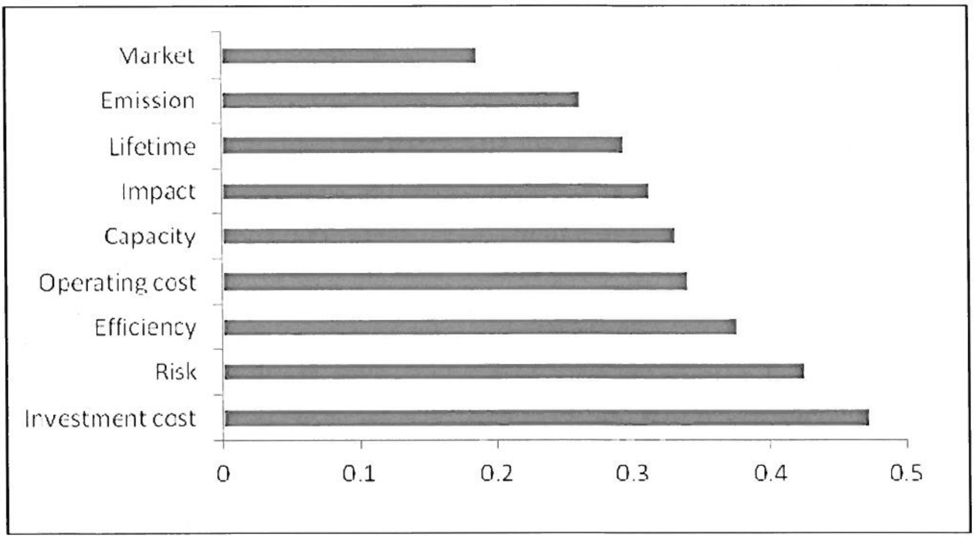

Fig. 4. The priority numbers of sub- criteria for selection the wind production farm

As seen in Figure 4, the investment cost (0.472), and risk (0.425) covered by economic and environmental criteria, respectively have the highest priority numbers. Sub-factors such as lifetime (0.294), emission (0.263), and potential to the electricity market (0.187) have the lowest priority number. So, the priority value of the investment cost and risk criteria was determined as more important than the priority value of the market, emission, and lifetime while identifying the region which has the highest capacity to produce wind energy.

The final ranking of the alternative sites as shown in Table 4 are calculated to combine the scores of each alternative.

Table 4. The ranking of alternatives to generate wind power

Alternatives	Score	Rank
Tekirdag	0.237	2
Corlu	0.368	1
Edirne	0.181	4
Krklareli	0.194	3

According to the results shown in Table 4, the best alternative is found to be Corlu region. The rank order of alternative areas from the best to the worst is obtained as Corlu (0.368), Tekirdag (0.237), Krklareli (0.194), and Edirne (0.181), respectively. Corlu location is expected to be the best site mainly because it has the best performance under three merits. In other words, Corlu site must be primary location as much as possible for wind energy production in Marmara region of Turkey. Also, note that, Edirne location has a performance worse than the other stations.

CONCLUSION

Energy investment decisions are inherently multi-objective in nature. MCDM methods can help governments to evaluate energy sector plans and policies. In this study, a hierarchical decision making structure that uses AHP to prioritize preferences for wind energy production regions located in Marmara region of Turkey according to various criteria named economic, technical, and environmental attributes was suggested. The results of the proposed methodologies show that the best locations for wind generation are Corlu, Tekirdag, Krklareli, and Edirne, respectively. In summary, the proposed FAHP can be used to evaluate various management strategies and thus resources can be effectively deployed to strengthen these aspects of project management. In addition, the proposed approach can help governments to gain information about the wind energy production regions in the Marmara region of Turkey. This model is helpful for energy planners and wind farm owners for future planning. Furthormore, this study helps electricity companies for optimal and determine effective allocations of their budget. In the future, the proposed methodology can be applied for different regions which have the wind energy potential.

Renewable energy strategy of Turkey in near future is primarily based on maximization of the exploitation of economically feasible hydropower and wind energy potential of the country. Thus, the utilization of all kinds of indigenous energy sources available in the country has a vital importance in meeting the energy demand of the country. Turkey, as an emerging economy, has been having a growing energy demand over the last decades and it is expected to continue in coming years. In this way, effective utilization of renewable energy potential in Turkey can be provided and sustainable development may be maintained through reducing the dependence of energy sector of the country on foreign energy supplier. The wind sector is a good example of the increasing interest in generation of electricity with renewable resources. Turkey has the potential to secure its long term energy future through focus on increasing utilization of renewable energy. In the case of Turkey, renewable energy resources including wind energy do not have wide applications due to some technological and economic constraints. Investments in wind energy, starting from Marmara and the Aegean coast, which has the highest wind energy potential should be initiated quickly. Conclusively, the use of present wind energy potential is very important from both economical and environmental respects. It is not enough for government to support the development of renewable energy technologies including wind energy. The Turkish government must also support the commercial applications of renewable energy, especially wind energy, in the country.

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