A Multivariable Model for Identification of Preferred Location of Wind Plants

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Abstract - Unique features of renewable energies such as wind energy has caused increasing demands for such resources. In order to use wind energy as a natural resource, environmental circumstances and geographical location related to wind intensity must be considered. Different factors may affect on the selection of a suitable location for wind plants. These factors must be considered concurrently for optimum location identification of wind plants. This article presents an integrated approach for location of wind plants by Data Envelopment Analysis (DEA). Furthermore, an integrated DEA approach incorporating the most relevant parameters of wind plants is introduced.The prescribed approach is tested for twenty five different cities in Iran. This is the first study that considers an integrated DEA approach for geographical location optimization of wind plants. Implementation of the proposed approach would enable the energy policy makers to select the best possible location for construction of a wind power plant with lowest possible costs.

Keyword: Wind Plants,DEA,location Optimization

I. INTRODUCTION

THE increase in negative effects of fossil fuels on the environment has forced many countries, especially the developed ones, to use renewable energy sources.Currently the fastest developing energy source technology is wind energy. Because wind energy is renewable and environment friendly, systems that convert wind energy to electricity have developed rapidly. Wind energy is an alternative clear energy source compared to the fossil fuels that pollute the lower layer of atmosphere.

In order to harness wind-power, the initial step should be to determine the potentiality of the wind-power as well as features of the wind-power in the possible region or area. Regarding the reliability of wind-power measurements, determination of where to build wind observation station (WOS) is very important. An ideal location for such center should particularly be able to represent the area. The bulletin for wind and solar measurements came into force after being published in the Official Gazette, with a number 24903, on 11th October 2002. This announcement involves criteria for the measurements that form the basis of constructing a production center dependent upon wind and solar energy. According to these criteria, it was selected the ideal location for a WOS, which will function as determining the characteristics of the wind in the region of Eskisehir by taking advantage of AHP.

Energy is a major commodity that furnishes the fundamentals of every human activity for reasonable and good life quality. It is a continuous driving power for the social and technological prospective developments. Energy sources are vital and essential ingredients for all human transactions and without them human activities of all kinds will not be progressive at all. On one hand, the energy sources are limited and on the other hand, the population growth at present average rate of 2% inserts extra pressure on additional energy demands. We are moving towards the situation under which there'll be no longer inexpensive energy resources availability. There are a number of different energy cost categories, which ought to be taken into consideration as listed below [2]:

1) Impact on human health
2) Environmental damages
3) Long-term cost of resource depletion
4) Subsidies for research and development, operation costs, infrastructure and evacuation in cases of accidents
5) Cost of an increased probability of wars due to Securing energy resources and proliferation of nuclear weapons
6) Cost of radioactive contamination of production equipment and dwellings after major nuclear accidents
7) Psycho-social costs

It has been recently realized that renewable energy sources and systems such as wind energy can have a beneficial impact with regard to essential technical, environmental, and political vision. Hence, newly emerging renewable alternative energy resources are expected to take increasing role in the energy scenarios of the future energy consumptions.

Wind energy is the most ancient source, and it is the root material for almost all fossil and renewable types. Wind energy is freely available and could be easily harnessed to reduce our reliance on hydrocarbon-based energy by both, passive and active designs.

In a study, the aim was to determine the most convenient location for a wind observation station to be built on the campus of a university using analytic hierarchy process (AHP).[1]

AHP is used to solve complex decision-making problems in different areas, suchas planning [3]. choosing the best policy after finding a set of alternatives [4] .AHP is a popular method used in finding a solution to the problem of location selection. Tzeng et al. [5]
A survey of many distinct applications of location models is provided by Eiselt (1992)[6], ranging from traditional applications involving newspaper transfer points (Jacobsen and Madsen, 1980)[7], solid waste transfer points (Marks and Liebman, 1971[8]; Wirasinghe and Waters, 1983)[9], bank branches (Hopmans, 1986)[10], and motels (Kimes and Fitzsimmons, 1990)[11] to the more unusual location problems such as the location of a church camp (Huxley, 1982)[12], the determination of apparel sizes (Tryfos, 1986)[13], ingot sizes (Vasko et al., 1987)[14], and the location of rain gauges (Hogan, 1990)[15].For a list of new location applications, readers are referred to Current et al. (2002).

From the viewpoint of incorporating qualitative factors in the location decision, the most widely used technique is a weighted checklist approach in which various important but diverse factors like proximity to customers, business climate, legislation, tax incentives and other support factors are rated on a weighted scale and combined into an aggregate score. The selected site is the one with the best aggregate score. Details and applications in a wide variety of industries are reported by Bowersox and Closs (1996)[16], Chase et al. (1998)[17], Ballou (1999)[18] and Krajewski and Ritzman (1999)[19] among others. Such an approach can lead to subjective results depending on the preferences of the decision-maker. Moreover, there has been little attempt in previous research to measure the effectiveness of such a weighting mechanism.

Schmenner (1982)[20] tested the significance of qualitative variables for the plant location decision and reported a comprehensive survey of the plant location/re-location practices among Fortune 500 companies in the US. The study identified favorable labor market, nearness to market, quality of life in the area, nearness to supplies, low labor rates as the most important variables considered by managers in the location decision.

For challenging the problems of these models we have presented a new methodology for assessment of wind-power in selected regions and have used a multivariable methodology named data envelopment analysis (DEA) for location of a wind plant with regard to characteristics of each area. The structure of DEA model is provided below

II. THE MULTIVARIATE MODEL

In this article we have used DEA for identification of optimum location for wind devices. For this purpose we have defined a set of wind devices parameters that affect on choosing a special place to use for installing wind devices between other places. With regard to our studies about wind power models number of local and geographical parameters have been defined and these parameters were considered as inputs and outputs of DEA model. In this way Wind speed , Quantity of proper geological areas And Quantity of proper topographical areas are considered as output parameters. Theses three indicators are the most important parameters that affect on wind efficiency of a special region.

Furthermore two non-geographical parameters have been presented: distance of power distribution network and cost of wind devices. One of the more important uses of wind energy is for the rural regions that cost of supplying electricity from power grids for them is too much so for this areas the local power stations is considered. The nature of wind energy is local. Therefore the distance from power distribution grid is a vital factor for determination using wind energy. If the distance is too much, supplying from power grids will be too expensive. In this case the wind plants as a local energy supplier is a good choice but the distance of power grid is a main parameter. Therefore we have chosen this parameter as one of our indicators. Finally cost of wind devices in each location is considered as one of our indicators. It can be effective on decision making about a location. The parameter distance of power distribution network have an output structure in the related DEA model but other parameter, cost of wind devices and Intensity of natural disasters occurrence have input structure in our model. Using these parameters enables us to define a multi criteria method that uses several related parameters simultaneously and prevent the problems that exist in the original empirical and parametrical models.

The results of DEA model are validated by complarison with existing data. Finally we can determine the priority of our locations for construction of wind plants under consideration of DEA and PCA results. The structure of this method can be presented as a hybrid model as shown in Figure. 1.

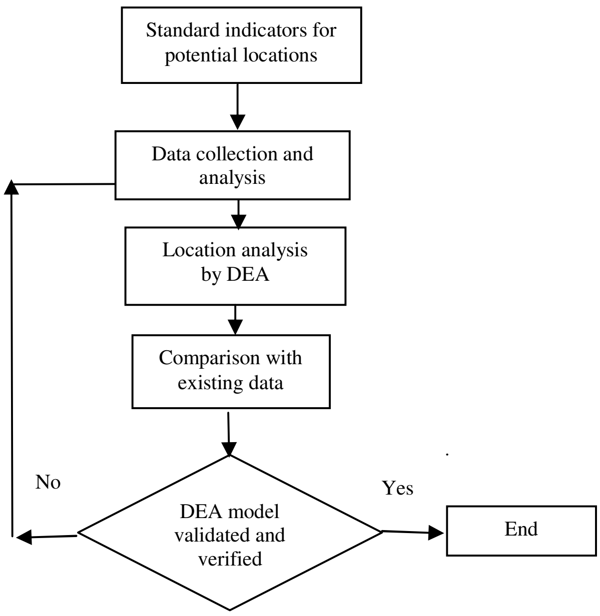

Figure. 1. Integrated model for location of wind plants

DEA is a methodology based upon an interesting application of linear programming. It has been successfully employed for assessing the relative performance of a set of firms, usually called decision-making units (DMU), which use a variety of identical inputs to produce a variety of identical outputs. The basic ideas behind DEA date back to Farrel [21], but the recent series of discussions started with the article by Charnes et al. [22]. We give very briefly the salient features of DEA. More detailed information can be obtained elsewhere [23-25].

As mentioned assume that there are *25* DMUs, and that the DMUs under consideration convert *2* input to 3 outputs. In particular, let the *m*th DMU produces outputs y_{jm} using x_{im} inputs. For the input parameter, cost of wind devices a constant value was considered so we assumed it equal to C = 1000 in all places. Estimating other parameter, distance of power distribution networks, was difficult and there was no clear information about it. So because lack of related data, we didn't use this parameter in our DEA model. To measure the efficiency of this conversion process by a DMU, a fractional mathematical programming model, denoted as Eq. (1) below, is proposed. The objective function of the model maximizes the ratio of weighted outputs to weighted inputs for the DMU under consideration subject to the condition that the similar ratios for all DMUs be less than or equal to one. That is:

$$\text{Max} \quad \frac{\sum_{j=1}^{J} v_{jm} y_{jm}}{\sum_{i=1}^{I} u_{im} x_{im}} \tag{1}$$

$$\text{Subject to:} \quad 0 \le \frac{\sum_{j=1}^{J} v_{jm} y_{jn}}{\sum_{i=1}^{I} u_{im} x_{in}} \le 1$$

n = 1, 2, …, N

$$v_{jm}, u_{im} \ge e$$

i = 1, 2, …, I

j = 1, 2,…, J

Where the subscript *i* stands for inputs, *j* stands for outputs and *n* stands for the DMUs. The variables v_{jm} and u_{im} are the weights to be determined by the above mathematical program. The term e is an arbitrarily small positive number introduced to ensure that all of the known inputs and outputs have positive weight values. The *m*th DMU is the base DMU in the above model. The optimal value of the objective function of Model 1 is the DEA efficiency score assigned to the *m*th DMU. If the efficiency score is 1 (or 100%), the *m*th DMU satisfies the necessary condition to be DEA efficient; otherwise, it is DEA inefficient. Note that the inefficiency is relative to the performance of other DMUs under consideration.

It is difficult to solve the above model because of its fractional objective function. However, if either the denominator or numerator of the ratio is forced to be unity, then the objective function will become linear, and a linear programming problem can be obtained. By setting the denominator of the ratio equal to unity, we can obtain the following output maximization linear programming problem, denoted as Eq. (2) below. Therefore it is possible to produce input minimization linear programming problem.

$$\text{Max} \quad \sum_{j=1}^{J} v_{jm} y_{jm} \tag{2}$$

$$\text{Subject to:} \quad \sum_{i=1}^{I} u_{im} x_{im} = 1$$

$$\sum_{j=1}^{J} v_{jm} y_{jn} - \sum_{i=1}^{I} u_{im} x_{in} \le 0$$

n =1, 2, …, N

$$v_{jm}, u_{im} \ge e$$

i=1, 2, …, I

j=1, 2,…, J

A complete DEA exercise involves solution of *25* such models, each for a base DMU (m=1, 2, …, 25), yielding *25* different set of weights (v_{jm}, u_{im}). In each model, the constraints are the same while the ratio to be maximized is changed.

DEA literature uses more advanced concepts such as the dual of the above program (Model 2), and incorporation of returns to scale. They are discussed elsewhere [23]. There are also many extensions to the basic models described here (e.g. [24]). Charnes et al. [25] have provided detailed accounts of the important developments in the history of DEA.

Thus, DEA has the ability to give a single index of performance, usually called the efficiency score, synthesizing diverse characteristics of different DMUs. Because of this ability, DEA has received numerous applications over the past two decades. Applications include the education sector [26,27], banks [28], health sector [29], environmental performance evaluation [30] and transport [31,32]. In this paper, DEA has been applied to study the location of wind plants. The DEA efficiency score of each location gives a rank for selecting a location as a wind plant.

III. MULTIVARIATE MODELS OF THE MULTIVARIETE MODEL

The values of parameters that have been chosen for DEA model were provided via the data of national meteorological organization of Iran. These data shows the case of wind power in Iran. As mentioned earlier of the four variables used in our study to locate the wind devices, cost of wind devices and Intensity of natural disasters occurrence are the input, while Wind speed , Quantity of proper geological areas And Quantity of proper topographical areas are the outputs. Further cost of wind devices is undesirable input.

A straightforward application of DEA to the data given in Table 1 is attempted. The relative efficiency scores are given in Table 2. The efficiency ratings shown in Table 2 are relative to the best location considered. The most efficient of all locations under consideration is assigned an efficiency score of 100%, while the ratings of others represent their ranking relative to the best location.

Twenty five cities in Iran have been considered as the case of this study and the results of it were analyzed. Our estimates about different wind parameters (input and output) in these cities are given in Table 1.

Table 1: The values of input and output parameters (indicators) for different cities

Name of location		Intensity of natural disasters occurrence	Wind speed (KNOTS)	Quantity of proper geological areas	Quantity of proper topographical areas	Distance of power distribution networks (Km)
	n	x_{1n}	y_{1n}	y_{2n}	y_{3n}	NA[1]
Abadan	1	19.4	9.7	36490.3	691.1	NA
Ahvaz	2	19.4	7.2	36490.3	691.1	NA
Ardestan	3	7.3	11.1	80296.3	10484.1	NA
Bandar abbas	4	14.9	9.1	55862.6	2854	NA
Birjand(khor)	5	20.4	16.1	226316.2	80892	NA
Boushehr	6	8.7	8.9	15747.9	891.2	NA
Hamedan	7	3	10.4	14928.7	274.5	NA
Karaj	8	5.6	8.1	27784.6	2898.4	NA
Kerman	9	12.9	9.6	153426.3	3154.4	NA
Kermanshah	10	4.2	8.0	16738.3	1745.7	NA
Khodabandeh	11	2	11.0	18064.1	1560.9	NA
Khoramabad	12	5.1	8.3	17827	1378.9	NA
Mahabad	13	8.9	10.5	24081.1	1755.2	NA
Manjil	14	7.7	23.9	10655.8	280.3	NA
Meimeh	15	8.3	10.5	80296.3	10484.1	NA
Neyshabor	16	20.4	8.4	226316.2	80892	NA
Oroumiye	17	12	6.3	24081.1	1755.2	NA
Sabzevar	18	18	9.6	226316.2	80892	NA
Shahrekord	19	3.7	8.6	11281	6.5	NA
Shiraz	20	24.3	6.4	83693.9	5725.9	NA
Tabriz	21	7.8	8.6	31271	1797.3	NA
Tehran	22	5.6	11.0	27784.6	2898.4	NA
Yazd	23	3.6	8.8	56358.9	11761.9	NA
Zabol	24	7.6	17.2	154642.3	10857.5	NA
Zahedan	25	7.6	9.7	154642.3	10857.5	NA

Table 2. Efficiency scores of wind places

DMU	Technical efficiency	Full efficiency	Ranking
Abadan	0.454	0.652	23
Ahvaz	0.351	0.630	24
Ardestan	0.708	0.942	11
Bandar abbas	0.458	0.744	22
Birjand(khor)	1.000	1.170	2
Boushehr	0.392	0.849	20
Hamedan	0.790	0.970	9
Karaj	0.493	0.915	16
Kerman	0.803	0.904	17
Kermanshah	0.538	0.941	12
Khodabandeh	1.000	1.040	5
Khoramabad	0.491	0.919	13
Mahabad	0.472	0.864	14
Manjil	1.000	1.280	1
Meimeh	0.625	0.918	15
Neyshabor	1.000	1.000	8
Oroumiye	0.295	0.768	21
Sabzevar	1.000	1.050	4
Shahrekord	0.585	0.947	10
Shiraz	0.388	0.560	25
Tabriz	0.412	0.871	18
Tehran	0.640	0.937	13
Yazd	1.000	1.020	6
Zabol	1.000	1.100	3
Zahedan	1.000	1.000	7

In this case Manjil has the best efficiency score between other places and it can be the best place for construction of wind plants. This is followed by Birjand and Zabol which are in the next positions.

Comparing the achieved results of this study with the results of the SANA studies reports (on the present wind farms and the under construction ones), the results are verified.

The results demonstrate that Manjil and its suburbs have the best performance (first rank). SANA studies also introduce Manjil and its suburbs, Harzevil and Siah Poosh, as the best locations. In SANA studies, Binalood wind farm that is in a region from Binalood Mountains up to Sabzevar suburbs is found as a suitable location. This region is found among the top ranked areas (Rank 4) in the present study results. Jarandigh, a suburb of Zanjan city, and Nosratabad of Zabol have high potentials for the purpose of constructing highly efficient wind farms, which have got Rank 3 and Rank 5 respectively, in the results of the subject study.

[1] Not Available

Table 3.: Critical indicators and sensitivity analysis of the model

DMU	Critical parameter	Sensitivity Analysis			
		x_{1n}	y_{1n}	y_{2n}	y_{3n}
Abadan	y_{2n}	7.59182	0	0	-24833.42
Ahvaz	y_{2n}	6.202205	0	0	-33206.92
Ardestan	y_{2n}	0	0	0	0
Bandar abbas	y_{2n}	0.943318	0	0	-35775.32
Birjand(khor)	y_{2n}	0	0	0	0
Boushehr	y_{2n}	0	0	0	-5319.002
Hamedan	y_{2n}	0	0	0	-1145.435
Karaj	y_{2n}	0	0	0	0
Kerman	y_{1n}	0	0	-1.36537	-42617.79
Kermanshah	y_{2n}	0	0	0	0
Khodabandeh	None	0	0	0	0
Khoramabad	y_{2n}	0	0	0	0
Mahabad	y_{2n}	0	0	0	-5716.561
Manjil	y_{2n}	0	0	0	0
Meimeh	y_{2n}	0	0	0	0
Neyshabor	y_{2n}	2.4	0	-1.2	0
Oroumiye	y_{2n}	0.124898	0	0	-20837.04
Sabzevar	None	0	0	0	0
Shahrekord	y_{2n}	0	0	0	-1418.749
Shiraz	y_{1n}	4.530627	0	0	-62138.44
Tabriz	y_{2n}	0	0	0	-1444.166
Tehran	y_{2n}	0	0	0	0
Yazd	y_{3n}	0	0	0	0
Zabol	y_{2n}	0	0	0	0
Zahedan	y_{2n}	0	0	-7.5	0

Analyzing the results of DEA model shows that the wind speed is the most important parameter between the effective parameters of wind plants and so for specifying the location of power plants it must be considered more than other parameters.

In this way the amount of independence of each parameter from other parameters is detected. So we can eliminate unnecessary parameters and use other parameters to upgrade our model. Wind speed is critical parameter for all DMUs. If DMU of Manjil is eliminated, next three DMUs – Birjand, Zabol and Sabzevar - adopt rank 1 in related DEA model. For DMU of Kerman and Shiraz, Quantity of proper geological areas is critical parameter while for Yazd the critical parameter is Quantity of proper topographical areas. There is no critical parameter for DMU of Khodabandeh and Sabzevar.

VI. SUMMARY AND CONCLUSION

Environmentally friendly benefits of wind power plants make them very desirable. Hence determination the optimum locations for use of this resource is a vital decision. Generally, there are several parameters models that are used to specify the locations of wind plants. But, because of problems with these models, there are great amount of uncertainly in using them and many of them are local models that only can be used for specific places. In this article we proposed a Multivariable Model (DEA) approach that uses a number of predefined parameters that can be used to identity optimum locations of wind power plants in a country, region, etc. DEA is used to rank various locations capabilities with respect to four outputs and one input. Furthermore existing data is also used to verify and validate the DEA results. The integrated approach has been applied to twenty five different locations in Iran and may be easily used for other countries or regions. This would result in significant saving when compared with conventional methods of measurements for location optimization.

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