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The Selection of Renewable Energy Power Plant Technology Using Fuzzy Data Envelopment Analysis

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Abstract—**The efficiency of resource utilization and sustainability are rising values all over the world. Power generation technologies have an important weight in this manner for a sustainable future. Particularly, renewable energy power technologies should take over the non-renewable power generation technologies when considered on environmental issues. However it is too far to substitute renewable onto non-renewable as for now. At this point, there is another issue for choosing the best yet suitable alternative technology. The selection problem is a difficult multi-criteria decision making problem in many fields as well as in the selection of power generation technology. This paper proposed a data envelopment analysis model approach by using triangular fuzzy numbers (TFN) as the solution. Six different technologies were used as the decision making units (DMU). Inputs and outputs variables were selected in general indicators such as economical and technical. It was showed that policy and decision makers could follow this methodology to produce effective solution for energy generation problems.**

Index Terms— **Fuzzy data envelopment analysis, effectiveness, multi-criteria decision making, renewable energy**

I. INTRODUCTION

Energy demands are increasing all over the world based on the growing population, development level, expanding industrial areas. Due to booming energy demand, countries faced with energy scarcity. The greatest economy in the world, the US economy has been supplied by energy obtained from fossil fuels almost 85% of its demand [1], [2].

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To make a long term sustainable energy generation policies should be the main priority of governments. Searching new options for generating power brought to us clean energy generation technologies as it is called renewable energy power generation technologies. These technologies include on-shore wind power, off-shore wind power, geothermal power, solar power, photovoltaic power and small hydropower. There is a strong relationship between increasing of CO_2 emissions and increased usage of non-renewable energy resources. Increased renewable energy resources usage can help to reduce CO_2 emissions. On the other hand, the usage of limited fossil fuel resources has severe environmental effects.

These technologies are relatively new technologies and need higher investment capital than the older technologies. Due to this disadvantage, the selection problem of technology is naturally an important multi-criteria decision making problem. This study focuses on the selection process by using data envelopment analysis (DEA) which is well known alternatives assessment method. It is selected 6 different technologies as decision making units (DMU) and determined two groups of variables such as economical and technical. Based on the assessment of decision makers it is obtained linguistic variable values for these groups. Fuzzy data envelopment analysis (FDEA) model proposed by Lertworasirikul [3] and Lin [4], possibility Charnes Cooper Rhodes model (PCCR1) was used to solve this problem with α-cut approach in six α-levels.

The rest of this paper is organized as follows. Section 2 presents recent literature of Data Envelopment Analysis on the energy and the selection problems. Methodology and proposed method is given in section 3. Section 4 is devoted an illustrative example problem on the selection of renewable energy power generation technologies. Section 5 presents a conclusion.

II. LITERATURE REVIEW

There are numerous performance evaluation studies using DEA and its variation. Since our problem is the selection of energy power generation technology, in this study we focused on two aspects of literature: various energy application and selection problem. As below we briefly reviewed the related literature.

Zhou et al. [5] published a comprehensive literature survey on the application of data envelopment analysis (DEA) to Energy and Environment (E&E). They classified the 100 publications in this field and mentioned some issues usage of DEA in E&E studies. In this survey it can be found many theoretical and practical studies on E&E. Sarkis and Talluri [6] focused on the evaluation of eco-efficiency. They demonstrated a usage of Data Envelopment Analysis in the environmental performance evaluation. They showed the advantages and disadvantages of methodology. Kumar and Shrestha [7] assessed the efficiencies of hydropower plants of Nepal Electricity Authority (NEA) using data envelopment analysis. They used input minimization approach in the various models. They used GAMS solver and exercised sensitivity analysis. Ahmad et al. [8] build a model to assess the performance of Small to Medium-Sized Manufacturing Enterprises (SMEs). This model was an integrated model in the Data Envelopment Analysis and the Analytical Hierarchy Process (AHP). They obtained reasonable and sensible results. Lee et al. [9] used the hybrid model of data envelopment analysis and analytic hierarchy process for determining a contemporary energy policy of Korea in 2006-2015. They proposed a multi-criteria decision making support tool for policy makers. Kongar and Rosenrater [2] conducted a research on energy technology selection. They ranked the alternatives by using two conventional data envelopment analysis models. They handled the alternatives together without distinction of renewable or non-renewable. Guo [10] applied the fuzzy data envelopment analysis on the site selection problem for a restaurant. The problem was solved in uncertainty conditions. It was considered that the rent of establishment, amount of traffic, level of security, the consumption level of consumer and competition level as primary factors. A good solution for the location of the restaurant was obtained. Rabbani et al.[11] developed a supplier selection model based on FDEA, TOPSIS and Goal Programming. They ranked the accepted orders first, and then goal programming supplier selection model was used in the second phase by using time, cost and quality criteria. Song et al. [12] evaluated the performance of Chinese coal industry with data envelopment analysis (DEA) based on 2007 statistical data. As a result they considered the problem in a sustainability context and advised some policies. Lin [13] studied on a personnel selection problem. It was used FDEA and ANP approach systematically. Linguistic variables were found and quantified based on Liang and Wang paper. Then possibilistic fuzzy DEA model (PCCR1) proposed by Lertworasirikul was used to solve the problem. Effectiveness values of applicants were found and they were ranked accordingly [3], [4]. Azadeh and Alem [14] studied on a vendor selection problem in a supply chain. They had three types of problems and used mainly the data envelopment analysis DEA and its variations such as fuzzy data envelopment analysis FDEA and chance constraint data envelopment analysis CCDEA as solution techniques. They solved these three models in the context of certainty, uncertainty and probabilistic conditions. Then results were compared. Zamani et al. [15] presented an application of hard decision making problem, the selection of the right IT infrastructure for the smart grid. They used fuzzy data envelopment analysis as solution methodology. They benefited from FDEA solution instead of ad hoc, heuristic and subjective solutions. Azadeh et al. [16] investigated optimum location identification of wind plants in Iran. They used hierarchical Data Envelopment Analysis and justified their method Principal Component Analysis (PCA) and Numerical Taxonomy (NT). Their purpose was to give a tool to the policy makers when they decide the suitable location for wind power plants. Azadeh et al. [17] proposed an integrated method to measure efficiency of wireless communication sectors with ambiguous data based on data envelopment analysis and fuzzy data envelopment analysis (FDEA). They used the indicators of the International Telecommunication Union (ITU) data as variables. Alizadeh et al. [18] applied the data envelopment analysis in a fuzzy environment for the solution of an allocation problem. They used traditional DEA and multi-criteria DEA and obtained a fuzzy multi-objective non-linear programming. They solved the model with fuzzy parametric programming (FPP) and minimum deviation method.

III. METHODOLOGY

A. *Data Envelopment Analysis*

Data envelopment analysis is a well known technique which measures relative efficiency of decision making units in a homogenous set. Since the first appearance of Charnes, Cooper and Rhodes (CCR) model in 1978, DEA has an enormous body of literature [19]. It is a very useful measurement technique, so there have been widespread applications in every field. One of the basic output oriented CCR's mathematical models is given as follows [4]:

$$\frac{1}{h_k} = Min\sum_{i=1}^{m} v_i X_{ik}$$

S.T.

$$\sum_{r=1}^{s} u_r Y_{rk} = 1$$

$$\sum_{i=1}^{m} v_i X_{ij} - \sum_{r=1}^{s} u_r Y_{rj} \geq 0, \qquad j = 1,\dots,n. \tag{1}$$

$$v_i, u_r \geq \varepsilon, \quad r = 1,\dots,s, \quad i = 1,\dots,m$$

Where; h_k is the relative efficiency of DMU k and X_{ij} denotes the input amount of X_i for DMU j, and Y_{rj} is the output amount of Y_r for DMU j; v_i and u_r are weights attached to X_i and Y_r, respectively, and ε is a small non-Archimedean number.

According to Lin's approach, Technology (T_j) denotes DMU j and evaluation of T_j under C_r represented by Y_{rj}. The input amount is not taken into account, so we measured the effectiveness. The relative effectiveness of DMU k, represented by E_k and Model (1) can be converted Model (2) based on Lin and Kao et al. approach using one input which is equal to one [4], [20].

$$\frac{1}{E_k} = Min\ v_1$$

S.T.

$$\sum_{r=1}^{s} u_r Y_{rk} = 1$$

$$v_1 - \sum_{r=1}^{s} u_r Y_{rj} \geq 0, \qquad j = 1,\dots,n. \tag{2}$$

$$v_1, u_r \geq \varepsilon, \quad r = 1,\dots,s$$

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B. *Fuzzy Data Envelopment Analysis*

Uncertainty situation is an inseparable part of real life problems. We can handle this issue by using fuzzy approach. Also in DEA literature, it has developed and used many fuzzy DEA model [3],[4],[10],[14],[15],[17],[18].

Moreover, Model (2) modified to a fuzzy version of DEA, possibility CCR (PCCR1) originated by Lertworasirikul [3], [4]. In this model, output variables are defined as triangular fuzzy numbers. Triangular fuzzy numbers represented by $\tilde{y}_{rj}$ for each Y_{rj} and using six different level of α (0, 0.2, 0.4, 0.6, 0.8, and 1), the possibility DEA–CCR model is established as follows [4]:

$$\frac{1}{E_k} = Min\ v_1$$

S.T.

$$\begin{aligned}
&\sum_{r=1}^{s} u_r (\tilde{y}_{rk})_\alpha^U \geq 1, \\
&\sum_{r=1}^{s} u_r (\tilde{y}_{rk})_\alpha^L \leq 1, \\
&v_1 - \sum_{r=1}^{s} u_r (\tilde{y}_{rj})_\alpha^U \geq 0, \quad j = 1,\dots,n, \\
&v_1, u_r \geq \varepsilon, \quad r = 1,\dots,s.
\end{aligned} \tag{3}$$

Model (3) measure the relative effectiveness of DMU k. If E_k is greater or equal to 1 for any α levels k^{th} DMU is possibilistic effective accordingly, otherwise it is possibilistic ineffective with respect to Lertworasirikul's et al. [3] inferences.

IV. IMPLEMENTATION AND RESULTS

A. *Economical and Technical Criteria*

We defined two groups of criteria such as technical and economical criteria based on the previous report by Lako [21]. Technical criteria were divided into four sub-criteria; Construction period (SC1), Technical lifetime (SC2), Capacity factor (SC3) and Maximum availability (SC4). Economical criteria were divided into three sub-criteria; Investment cost (SC5), Fixed & variable O&M cost (SC6) and Progress ratio (SC7). We described six different renewable energy power sources as DMU's. This is summarized in Table 1 and Table 2.

TABLE I
SUMMARY of SELECTED CRITERIA and SUB-CRITERIA for the EVALUATION

Main Criteria	Sub-criteria
Technical Criterion (C1)	Construction period (SC1) Technical lifetime (SC2) Capacity factor (SC3) Maximum availability (SC4)
Economic Criterion (C2)	Investment cost (SC5): Fixed & variable O&M cost (SC6) Progress ratio (SC7)

TABLE II
DECISION MAKING UNITS

	DMU's
DMU1	Onshore wind (T_1)
DMU2	Offshore wind (T_2)
DMU3	Geothermal power (T_3)
DMU4	Solar power (T_4)
DMU5	Photovoltaic power (T_5)
DMU6	Small Hydropower (T_6)

B. *Assessment of Technologies under Criteria*

Subjective evaluation of decision makers on Technologies are defined linguistic variables by using Lin's approach in 5 levels such as Very Good (VG), Good (G), Fair (F), Poor (P), Very Poor (VP) [3], [13], [22]. We modified the interval as [0,100]. Table 3 summarized the rating scheme. Two decision makers conducted an evaluation by using this scheme. Table 4 shows a sample evaluation.

TABLE III
LINGUISTIC VARIABLES and TFN

Linguistic Variable	TFN
Very good (VG)	(80, 100, 100)
Good (G)	(60, 80, 100)
Fair (F)	(30, 50, 70)
Poor (P)	(0, 20, 40)
Very poor (VP)	(0, 0, 20)

TABLE IV
SAMPLE ASSESSMENT RESULTS of T_1 UNDER C1

Sub-criteria	Decision-maker-I Linguistic data
SC1	Very Good (VG)
SC2	Fair (F)
SC3	Poor (P)
SC4	Very Good) VG
SC5	Good (G)
SC6	Fair (F)
SC7	Good (G)

As a result of this evaluation we obtained TFN values of outputs in Table 5. We imposed these values possibilistic DEA model at six α level and solved these models by using interval programming. Table 6 shows DEA models solutions and ranking of Technologies with respect to average E_k values.

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TABLE V
TFN RATINGS of SIX RENEWABLE ENERGY TECHNOLOGIES BASED on ASSESSMENTS of DMU'S.

	$\tilde{y}_{1j}$	$\tilde{y}_{2j}$
T1	(360; 500; 610)	(385; 525; 625)
T2	(300; 420; 530)	(295; 435; 565)
T3	(295; 415; 515)	(300; 420; 530)
T4	(220; 340; 470)	(205; 335; 465)
T5	(335; 465; 555)	(270; 410; 520)
T6	(320; 460; 580)	(345; 485; 595)

TABLE VI
E_k VALUES and RANKING w.r.t. AVERAGE E_k

	Alfa=0	Alfa= 0.2	Alfa= 0.4	Alfa= 0.6	Alfa= 0.8	Alfa=1	Average	Rank
DMU1	1	1	1	1	1	1	1	1
DMU2	0.9038	0.9035	0.9032	0.9029	0.9026	0.9022	0.9030	4
DMU3	0.8480	0.8475	0.8470	0.8465	0.8460	0.8455	0.8468	5
DMU4	0.7704	0.7696	0.7688	0.7681	0.7673	0.7665	0.7685	6
DMU5	0.9094	0.9091	0.9088	0.9085	0.9082	0.9079	0.9087	3
DMU6	0.9520	0.9518	0.9517	0.9515	0.9514	0.9512	0.9516	2

V. Conclusion

In this homogenous set we obtained that on-shore wind power (DMU1) is possibilistic effective relatively. The second alternative is the small hydropower as the off-shore wind power and the photovoltaic power although they are not possibilistic effective. If we focus on the investment cost of on-shore wind power it is realized that it is the cheapest among them [22]. Although we cannot achieve an exact judgment with this solution, it could be said that it is strong evidence on the on-shore wind power as an alternative. This superiority is a validation of FDEA model also.

We concluded that this approach is useful for policy makers instead of using just subjective evaluation. In this context it helps the decision makers. Future research could be done by extending the proposed method to the new fields.

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