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# SELECTION OF ELECTRIC ENERGY PRODUCTION TECHNOLOGIES USING DEA (CASE STUDY: IRAN)

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## ABSTRACT

Utilization of new energy technologies has been received a lot of attentions towards a sustainable energy system. In recent years, policy makers have to rethink on their strategies to warrant support for private sector efforts, including funding and other incentives. Considering energy technologies in terms of the sustainability practices is a complicated task. This paper intends to select and rank a number of technologies, in the context of the Iran Technology Foresight Program from a sustainable point of view. Therefore, data envelopment analysis (DEA) approach as a multi-criteria tool has been applied for energy production technology selection. This selection decision has been made based on decision makers' opinion in linguistic terms. To handle the subjectivity of decision makers' assessments, fuzzy logic has been applied.

***Keywords – Sustainability, Energy technologies, DEA, Linguistic terms, Fuzzy logic***

## 1. INTRODUCTION

Energy planning and policy making have attracted the attention of decision analysts for a long time, since the energy sector exhibits particular dynamics. Moreover, over the last decade, the impact of ''sustainability'' on the development of national and international policy has increased. It is realized that the energy sector and its contribution to the greenhouse effect should play a major role in the policy for a sustainable development (SD). In this context, efforts towards a sustainable energy system are progressively becoming an issue of universal concern and of paramount importance for most politicians and decision makers (Cornelissen, Van den Berg et al. 2001).

Efficient production, distribution and use of energy resources and provision of equitable and affordable access to energy while ensuring security of energy supply and environmental sustainability are some of the energy policy objectives towards a sustainable energy system. Implementation of new and innovative energy technology is key means of satisfying these objectives. Technological advances are of critical importance for the improvement of living conditions, the production and the transportation of the energy and the efficiency of its use thus it is expected to produce major public benefits (Sagar and Holdren 2002).

In recent years, due to the growth of knowledge about sustainable development, implementation of new and innovative energy technologies has been received a lot of attentions towards a sustainable energy system. Governments have to rethink on their strategies to warrant support for private sector efforts, including funding and other incentives. Considering energy technologies in terms of the sustainability practices is a complicated task and multiple criteria must be considered. This paper intends to select and rank a number of technologies, in the context of the Iran Technology Foresight Program from a sustainable point of view. Therefore, data envelopment analysis (DEA) approach as a multi-criteria tool has been applied for energy production technology selection. This selection decision has been made based on decision makers' opinion in linguistic terms. To handle the subjectivity of decision makers' assessments, fuzzy logic has been applied.

## 2. ENERGY TECHNOLOGY SELECTION

In the context of the Iran Technology Foresight Program, first of all, a working team was formulated, having eleven participants from all the relevant energy ''actors'' in Iran (Public Power Corporation– utility, independent power producers, financing organizations, relevant researchers and academics, governmental managers, the regulatory authority, the transmission system operator, the Center for Renewable Energy Sources) (Karbassi, Abduli et al. 2007; Ghobadian, Najafi et al. 2009; Moghaddam, Mousavi et al. 2012; Bahrami and Abbaszadeh 2013) to select the most appropriate energy technologies.The work team tried to examine technologies, which have not been used in the energy sector or have been introduced at a very small percentage, but are likely to support the four dimensions of sustainability, namely the economic, environmental, social and technological (Spangenberg, Pfahl et al. 2002). Finally, the following technologies, which match with the country's energy system specific requirements and based on literature (Doukas, Andreas et al. 2007; Aragonés-Beltrán, Chaparro-González et al. 2010) were chosen:

T1: The hydrogen technologies
T2: Geothermal
T3: The natural fossil fuels technologies
T4: Solar
T5: Wind
T6: Biomass

For the assessment of these technologies impact on the four dimensions of sustainability, the working team categorized a number of criteria, which are including:

C1: "Investment Cost" (IC) for economic aspect.
It refers to the economic magnitude expressing the cost for introducing a technology. It comprises the required costs for all the project implementation phases.

C2: "Effects on Natural Environment" (ENE) for environmental aspect.
It reflects the technology's intervention rate on the natural environment (noise, aesthetics' alteration, desolation).

C3: "Efficiency Rate" (ER) and C4 "Knowledge of the Innovative Technology "(KIT) for technological aspect.
"Efficiency rate" expresses the technology's ability to convert the primary energy source to electricity and "Knowledge of the innovative technology "represents the technology's maturity rate as well as its penetration percentage in the international market.

C5: "Contribution to Regional Development" (CRD) expresses the progress induced in the less developed regions of the country by introducing a new technology.

## 3. FUZZY SET THEORY

Zadeh (1965) introduced fuzzy set theory to cope with the imprecision and uncertainty which is inherent to the human judgments in decision making processes through the use of linguistic terms and degrees of membership (Zadeh 1965). In this work the technology's performance with respect to criteria are in linguistic terms on the basis of decision makers' opinion. Several functional forms of the membership function are available to represent different situations of fuzziness; for example, linear shape, concave shape and exponential shape. Two commonly used membership function types are linear triangular and linear trapezoidal membership functions. In this research, the trapezoidal membership function is utilized because of linear interpolation between fuzzy set elements. Trapezoidal membership function also gives reasonably good performance in terms of theoretical calculations as compared to other shapes. Thus, we set out trapezoidal membership functions for estimation of the technology's performance. A trapezoidal fuzzy number can be shown as $\tilde{w}=(a,b,c,d)$ in Fig.1. In addition, the definition of trapezoidal membership function is shown in Eq. (1). According to Eq. (1), if $b=c$ then the number is called a triangular fuzzy number (Amindoust 2012).

$$\mu_{\tilde{w}}(x)=\begin{cases} 0 \quad if \quad x<a \\ \frac{1}{b-a}(x-a) \quad if \quad a\le x\le b \\ 1 \quad if \quad b\le x\le c \\ \frac{1}{c-d}(x-d) \quad if \quad c\le x\le d \\ 0 \quad if \quad x>d \end{cases} \tag{1}$$

## 4. DATA ENVELOPMENT ANALYSIS

Data Envelopment Analysis (DEA) proposed by Charnes, Cooper, and Rhodes (CCR) (1978) is a mathematical programming method for assessing the relative efficiency of homogenous decision making units (DMU) with multiple inputs and outputs (Charnes, Cooper et al. 1978). One methods of data analysis and decision making is DEA. It is one of the most used standalone techniques in making decision. DEA is a non-parametric method that lets efficiency be measured without having specific weights for inputs and outputs or specify the form of the production function.

In technology selection decision, the performance of an energy technology is calculated using the ratio of weighted outputs to weighted inputs (Amindoust 2010). The goal of the firm is to choose one or more technologies from "n" candidates. In order to calculate the set of efficiencies for "n" technologies, n fractional programming models are solved. The problem can be changed into linear programming. The model for technology k could be defined as follows Eq. (2).

$$\begin{aligned} &MaxZ_k=\sum_{r=1}^{s}u_r y_{rk} \\ &st: \\ &\sum_{i=1}^{m}v_i x_{ik}=1 \end{aligned} \tag{2}$$

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \le 0 \quad (j=1,2,\ldots,n) \qquad (1)$$

$$u_r, v_i \ge \varepsilon$$

Where: $k$ is the under evaluation unit; $s$ represents the number of outputs; $m$ represents the number of inputs; $y_{rj}$ is the amount of output $r$ provided by unit $j$; $xij$ is the amount of input $I$ used by unit ; $u_r$ and $v_i$ are the weights given to output and input respectively.

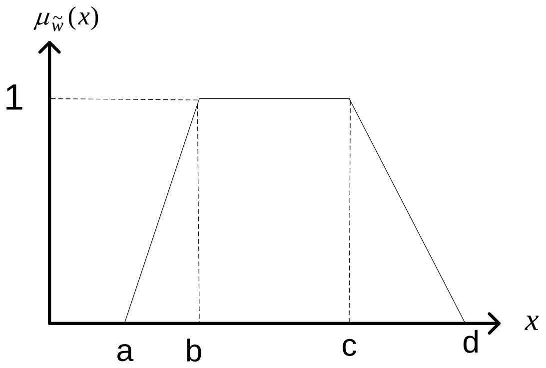


Figure 1 The trapezoidal fuzzy membership function.

## 5. METHODOLOGY OF WORK

This research was done based on the literature review involved in energy technology selection concluding “ which energy technology performance criteria to be considered” and “what methods to be applied for selection of such technologies”. These aspects are taken into account in energy technology selection to establish a useful decision model for manufacturing companies. The methodological flow of the work has been shown in Fig. 2.

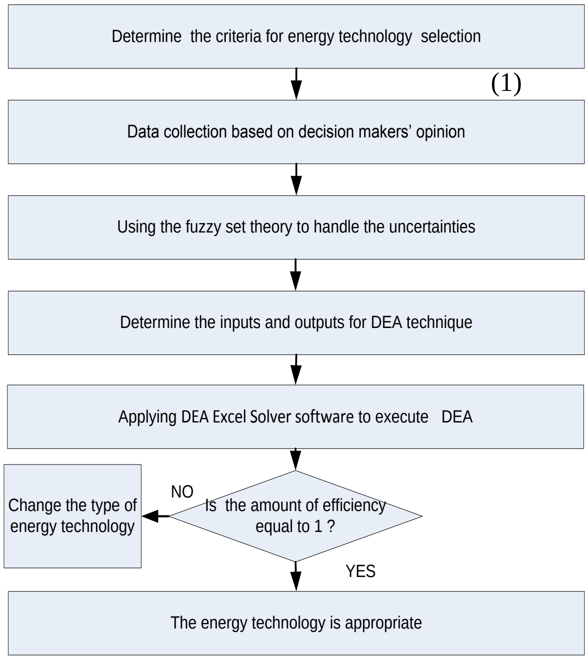


Figure 2 The methodological flow of the work.

## 6. EXERTION AND DISCUSSION

First of all, the membership functions have been applied for criteria to cope with decision makers’ opinion as seen in Fig. 3. In fact, this figure shows the range of criteria amount for technology performances. To define the technologies’ performances to each one of the criteria, several meeting were organized among working team. Therefore, considering membership functions of linguistic terms in Fig. 3, the obtained information about the energy technologies is shown in Table 1, which the related fuzzy numbers illustrated in Table 2.

Table 1 Fuzzy data for technology selection

| Energy Technologies | Inputs | | Outputs | | |
|---|---|---|---|---|---|
| | IC | ENE | ER | KIT | CRD |
| T1 | EP | MP | SP | MP | MP |
| T2 | SP | MP | WP | MP | WP |
| T3 | MP | WP | WP | WP | EP |
| T4 | SP | MP | EP | SP | MP |
| T5 | WP | EP | WP | EP | MP |
| T6 | EP | SP | SP | WP | SP |

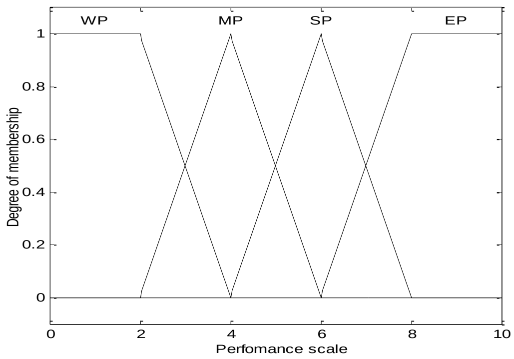


Figure 3 Membership functions of linguistic terms.

Table 2 The linguistic terms for technology's performance

| | |
|---|---|
| weakly preferred(WP) | (0, 0, 2, 4) |
| moderately preferred (MP) | (2, 4, 4, 6) |
| strongly preferred (SP) | (4, 6, 6, 8) |
| extremely preferred (EP) | (6, 8, 10, 10) |

Among deffuzzification methods, the center of area (COA) method which is the most popular method (Ordoobadi 2009) is applied in this paper as shown in Eq. (3).

$$x_{COA} = \frac{\sum_{i=1}^{n} x_i . \mu_i(x_i)}{\sum_{i=1}^{n} \mu_i(x_i)} \quad (3)$$

where, $x_i$ is an element in the set $X$ and $x_{COA}$ is the deffuzzified output. The results of Table 1 are deffuzified and then normalized as shown in Table 3.

By applying DEA Excel Solver software and implementing DEA model considering Table 3 as inputs and outputs data, the efficient and inefficient technologies are identified as shown in Table 4.

Table 3 The input and output data of DEA model

| **Energy Technologies** | **Inputs** | | **Output** | | |
|---|---|---|---|---|---|
| | **IC** | **ENE** | **ER** | **KIT** | **CRD** |
| T1 | 0.844 | 0.400 | 0.600 | 0.400 | 0.400 |
| T2 | 0.600 | 0.400 | 0.208 | 0.400 | 0.208 |
| T3 | 0.400 | 0.208 | 0.208 | 0.208 | 0.844 |
| T4 | 0.600 | 0.400 | 0.844 | 0.600 | 0.400 |
| T5 | 0.208 | 0.844 | 0.208 | 0.844 | 0.400 |
| T6 | 0.844 | 0.600 | 0.600 | 0.208 | 0.600 |

It has been explained before in section 4 that the efficiency equals to ratio of weighted outputs to weighted inputs. To implement DEA model, the input and output dimensions must be defined firstly. Normally, the criteria which the smaller is better consider as inputs and the criteria which the larger is better consider as outputs to increase the efficiency. So in this research IC and ENE are considered as inputs and ER, KIT, and CRD are considered as outputs.

Table 4 Efficiency values and optimal multipliers of technologies

| **Input-Oriented** | | | | | | |
|---|---|---|---|---|---|---|
| | CRS | Optimal Multipliers | | | | |
| **DMU No.** | Efficiency | IC | ENE | ER | KIT | CRD |
| **1** | 0.753 | 0.000 | 2.500 | 1.010 | 0.000 | 0.367 |
| **2** | 0.667 | 0.667 | 1.503 | 0.000 | 1.667 | 0.000 |
| **3** | 1.000 | 2.500 | 0.000 | 0.000 | 0.000 | 1.184 |
| **4** | 1.000 | 1.666 | 0.000 | 1.184 | 0.000 | 0.000 |
| **5** | 1.000 | 0.473 | 1.068 | 0.000 | 1.184 | 0.000 |
| **6** | 0.628 | 1.137 | 0.067 | 0.652 | 0.000 | 0.394 |

Technologies T1, T2, and T6 are inefficient because their efficiency is less than one but the others, which obtained the efficiency equal to one, are efficient. In Table 4, the optimal weights for inputs and outputs are shown. As seen in Table 4, in some cases the weights are considered equal to zero and it is a drawback of DEA (Amindoust, Shamsuddin et al. 2013; Amindoust, Ahmed et al. 2014). It is not justice to omit some elements from an eleven participant's point of view. Therefore, it is better to shift these weights. The target value for inputs and outputs are calculated as shown in Table 5.

Table 5 Target values for inputs and outputs

| Do. | Efficient Input Target | | Efficient Output Target | | |
|---|---|---|---|---|---|
| | IC | ENE | ER | KIT | CRD |
| 1 | 0.4655 | 0.3012 | 0.6000 | 0.4357 | 0.4000 |
| 2 | 0.4000 | 0.2666 | 0.5629 | 0.4000 | 0.2667 |
| 3 | 0.4000 | 0.2083 | 0.2083 | 0.2083 | 0.844 |
| 4 | 0.6000 | 0.4000 | 0.8444 | 0.6000 | 0.400 |
| 5 | 0.2083 | 0.8444 | 0.2083 | 0.8444 | 0.400 |
| 6 | 0.5303 | 0.3768 | 0.6000 | 0.4961 | 0.600 |

## 7. CONCLUSION

Today, the impact of ''sustainability'' on the development of societies has increased and sustainable energy system become a key issue for decision makers. In addition, utilization of new energy technologies is a main mean towards a sustainable energy system and currently policy considered. This paper selected a number of makers have to rethink on this. Considering energy technologies in terms of the sustainability practices is a complicated task and multiple criteria must be appropriate technologies, in the context of the Iran Technology Foresight Program from a sustainable point of view. Data envelopment analysis (DEA) approach as a multi-criteria tool was applied for energy production technology selection. This selection decision has been made based on decision makers' opinion in linguistic terms. To handle the subjectivity of decision Results show that the natural fossil fuels, Solar, and wind technologies are the most appropriate technologies in Iran. Makers' assessments, fuzzy logic were applied. Based on the results, the natural fossil fuels, Solar, and wind technologies are the most appropriate technologies in Iran.

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