A thorough evaluation of implementing geothermal energy for producing hydrogen in Iran using Data Envelopment Analysis(DEA)

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Abstract

Geothermal is a kind of renewable energy that is always available and can be harnessed continuously. Furthermore, the environmental pollution caused by its exploitation is far less than that created by conventional fossil fuels. Meanwhile, hydrogen has an extensive application in production of petroleum and petrochemical products and is therefore an important element of Iran's oil and gas reliant industry and economy. This paper investigates the potential of different provinces of Iran for producing hydrogen by a water electrolyzer using the electricity generated from a geothermal source. This objective is pursued by using the data envelopment analysis (DEA) method to rank and prioritize the provinces. Validity of the results obtained through this analysis was assessed by comparing them with results of TOPSIS, and VIKOR. In DEA model, the decision criteria were 13 measurable parameters, of which 5 were considered as input variables and 8 as output variables, and as mentioned above its decision-making units were the 14 Iranian provinces. The results showed that East-Azerbaijan, Bushehr and Hormozgan have the highest priority and Kerman and Sistan-Baluchistan have the lowest priority for hydrogen production via geothermal power assisted water electrolysis.

Keywords

Geothermal energy; Hydrogen production; Data Envelopment Analysis; Prioritizing; Feasibility; Iran; Water Electrolyze.

1. Introduction

Geothermal energy is the thermal energy stored in underground layers of the earth, which is mostly harvested to generate electricity. Other major application of geothermal energy is the localized heating and cooling. Beside electricity and heat generation, geothermal energy have found applications in oil extraction, paper production, gold mining and processing, and production of silica dust (Yilmaz et al, 2012; SUNA, 2015).

Figure 1 shows a schematic illustration of a simple water electrolyzer. Water electrolyzers need some quantity of alkaline water and a strong electric current to produce pure hydrogen. In these systems, the flow of electricity in alkaline water releases oxygen molecules at anode and pure hydrogen molecules at cathode.

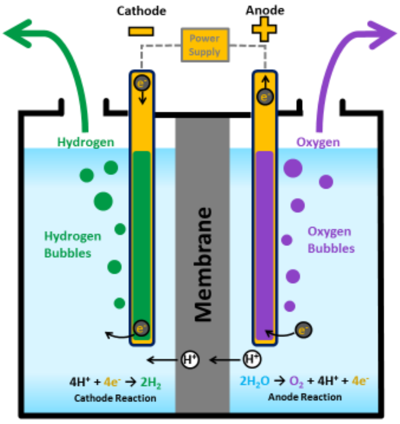

Figure 1. Schematic illustration of a simple water electrolyzer (Energy.gov, 2015)

Iran is a developing country with growing hydrogen-hungry oil, gas, petrochemical and nuclear industries, so it considers the acquirement of a stable supply of hydrogen as an imperative objective. Iran's geothermal electricity generation potential has provided an opportunity to use this energy for the process of water electrolysis and hydrogen production.

In this paper, we studied the feasibility and priority of different regions of Iran for hydrogen production via geothermal power assisted water electrolysis. This feasibility study and prioritization was performed by the use of multi-criteria decision-making methods including data envelopment analysis, TOPSIS and VIKOR.

2. Review of the Literature

In this section, the literature on geothermal energy and its related topics are reviewed. This section covers the environmental issues, performance, future prospects, and economic issues of geothermal power plants, methods of implementation and optimization of geothermal power assisted hydrogen production, and studies with similar methodologies in three sub sections: Geothermal source, Hydrogen, and DEA. There have been many research works related to hydrogen production from different renewable energy sources.

Posso et al (2016) assessed the hydrogen production potential by electrolysis in Ecuador from renewable sources of energy.

Lee and Hung (2012) analyzed economic development and competition between clean energy and fossil fuels considering advances in production of clean energy technologies.

Tolga Baltaa et al (2009) , discussed the geothermal-based hydrogen production methods, their technologies and application possibilities in their study. For a case study a high-temperature electrolysis process powered by geothermal energy was considered. Ouali et al (2011) , introduced hydrogen as a valuable energy resource.

Kanoglua et al (2007), proposed hydrogen liquefaction by geothermal energy and investigate three methods for liquefaction. Al-Zaharania et al (2013), studied about an improved performance integrated system to reduce greenhouse gas emissions.

Sigurvinssona et al (2007), believed that the high temperature improves the electrolysis process performance for hydrogen production. Alavi et al (2016a), analyzed hydrogen production from wind energy for southeastern part of Iran. Mostafaeipour et al (2016a), evaluated potential of wind energy for hydrogen production in the Fars Province of Iran. They found that hydrogen production from wind in city of Abadeh would be able to fuel approximately 22 cars per week by using EWT Direct wind 52/900 model turbine.

There are many renewable energy research works in the literature, but wind and solar share the highest among them. There are numerous wind energy articles that most of them evaluate energy potentials for generating electricity that could then be used to produce hydrogen (Mostafaeipour & Abesi, 2010; Alavi et al, 2016b; Mostafaeipour, 2013; Mohammadi et al, 2014; Shamshirband et al, 2015a; Mohammadi et al, 2016;

Mostafaeipour, 2014; Mostafaeipour, 2011; Mostafaeipour and Sadeghian, 2005). Solar energy can also produce electricity which could then produce hydrogen (Shamshirband et al, 2015b; Mostafaeipour et al, 2016b). Hybrid kind of energy like wind-solar can also be able to produce hydrogen too (Qolipour et al, 2016).

A study by Buonocore et al (2015), has assessed the life cycle and energy of a dry steam power plant in Tuscany Italy, which can produce electricity from locally available renewable energies, albeit with managed support of exhaustible energy sources. Yilmaz e al (2015), have performed a thermodynamic and economic analysis on hydrogen production via water electrolysis based on exergy of geothermal power plant. Gouareh, Settou, Khalfi, Recioui, Negrou, Rahmouni, and Dokkar (2015) have reported that power plants and refineries are the largest sources of carbon dioxide in Algeria. Yilmaz et al (2012), assessed 7 models for liquefying hydrogen via geothermal energy. They used the electrolysis process and high temperature steam electrolysis to produce hydrogen, used a geothermal binary power plant to produce electricity, and used a pre-cooled Linde-Hampson cycle to liquefy the produced hydrogen. Balta et al (2011), have analyzed the exergy, energy, cost and mass of a thermochemical chlorine-copper water-splitting cycle fed by geothermal energy.

In a study by Kanoglu et al (2010), authors defined and investigated 4 methods of hydrogen production via geothermal energy. Balta et al (2010a), analyzed the energy and exergy of geothermal energy-assisted hydrogen production via a four stage thermochemical chlorine-copper water-splitting cycle, and measured the energy and exergy efficiency of the process. Balta et al (2010b), have identified four potential methods of geothermal-assisted hydrogen production: 1) direct production from geothermal steam, 2) hydrogen production through water electrolysis using the electricity generated by geothermal power plant, 3) the use of geothermal heat and electricity for the electrolysis of high temperature steam and/or through combined process, 4) the use of geothermal heat in thermochemical processes to split the water into hydrogen and oxygen.

Author has performed numerous research works related to energy areas (Erratum to: shamshirband et al., 2016; Hosseini-Ezzabadi et al., 2015; Khorasanizadeh et al., 2014; Sajjadi et al., 2016; Shamshirband et al., 2015c).

3. Geographical Characyeristics

This study examined all geothermal fields in Iran to assess and rank them in terms of their feasibility for the production of hydrogen via a water electrolysis process that uses the electricity produced by the same geothermal field. According to a research conducted in 1999 by Iran's Renewable Energy Organization, these fields have been identified in almost all parts of the country (SUNA, 2015). Figure 2, in which geothermal fields are marked, shows the latest geothermal map of Iran according to a research conducted in 2010 by researchers of Kyushu University (Japan) (Yousefi et al, 2010).

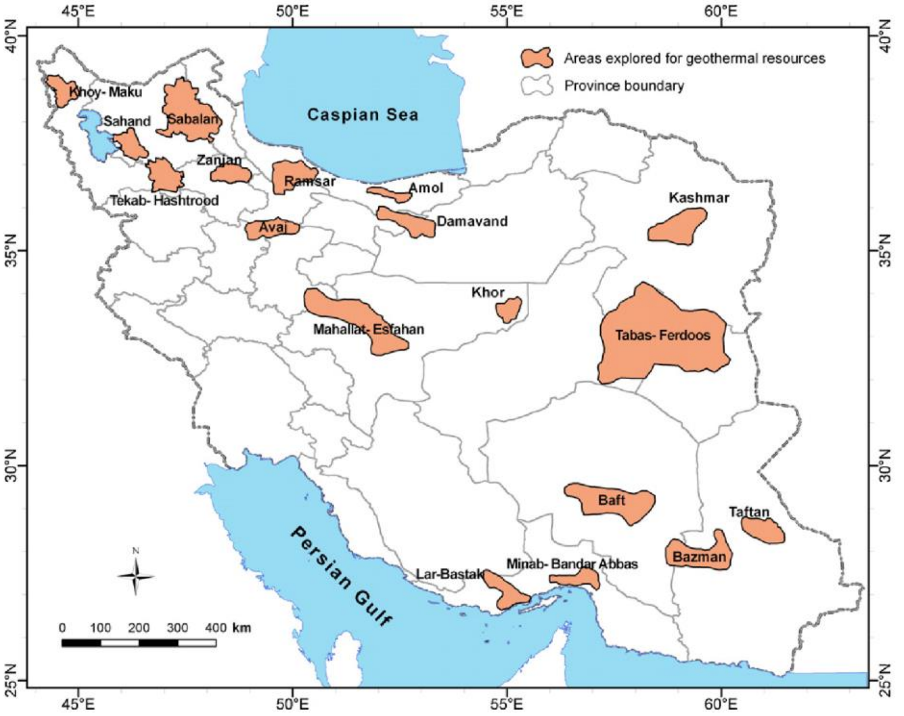

Figure 2. Geothermal Map of Iran (Yousefi et al, 2010)

3. Methodology

Data Envelopment Analysis (DEA) is a mathematical programming method for evaluating the efficiency of decision-making units (DMUs) with respect to a multitude of inputs and outputs. In 1957, Farrell evaluated the efficiency of production units through a method similar to those commonly used for performance measurement in engineering applications. Later, Charnes, Cooper and Rhodes developed the method described by Farrell, and introduced a model with multiple inputs and outputs that could evaluate the efficiency of unit; this model was called the data envelopment analysis or DEA (Khajavi et al, 2005).

Equation (1) shows the linear programming model in the DEA method. In this method, we first define a number of constraints and variables for the objective function and then try to maximize the relative advantage of unit *m* by assigning a set of weights for inputs and outputs. In this equation, Z_n denotes the relative efficiency of decision-making unit *n*, *i* is the index of input variable, *j* is the index of output variable, *N* is the number of studied decision-making units, *I* is the number of inputs, and *J* is the number of outputs of the model. Here, x_{in} represents the i-th input of n-th DMU, and y_{jn} represents the j-th output of n-th DMU, which are both different for different units. Vectors v_{jn} and u_{in} are the weights that must be optimized such that the relative efficiency of studied DMU get maximized. In fact, v_{jn} is the weight of j-th output of n-th DMU and u_{in} is the weight of i-th input of n-th DMU (Mirjalili et al, 2010). The maximum value that objective function can take is 1, which will mean that the studied DMU is efficient. When the obtained value is less than 1 , the studied DMU is called inefficient (Azadeh et al, 2011).

$$
\begin{aligned}
&\mathrm{Zn} = \mathrm{Max}\frac{\sum_{j=1}^{J} v_j y_{jn}}{\sum_{i=1}^{I} u_i x_{in}}\\
&\quad \text{St:}\\
&\quad 0 \le \frac{\sum_{j=1}^{J} v_j y_{jn}}{\sum_{i=1}^{I} u_i x_{in}} \le 1 \qquad , n=1,2,3,\ldots,N \qquad\qquad (1)\\
&v_j y_{jn} \ge \delta
\end{aligned}
$$

The model presented in Equation (1) has an infinite number of solutions. To overcome this issue, this non-linear model can be turned into a linear model through Change of variables (Mehregan, 2010). In the model of Equation (2), W_p is the relative efficiency of decision making unit *p*. This model seeks to determine the maximum output that can be obtained from the constrained inputs. X_i and Y_r represent k-th input and s-th output of the n-th studied unit respectively. Vectors *u* and *v* represent the weights of inputs and outputs for each unit (Mirjalili et al, 2010).

$$
\begin{aligned}
&W_p = \mathrm{Max} \sum_{r=1}^{s} v_r y_{rp}\\
&\quad \text{St:}\\
&\quad \sum_{i=1}^{k} u_i x_{ip} = 1\\
&\quad \sum_{r=1}^{s} v_r y_{rj} - \sum_{i=1}^{k} u_i x_{ij} \le 0 \qquad ,j = 1,2,\ldots,n \qquad\qquad (2)\\
&\quad u_i \ge 0 \qquad\qquad ,i = 1,2,\ldots,k\\
&\quad v_r \ge 0 \qquad\qquad , r = 1,2,\ldots,s
\end{aligned}
$$

If the number of DMUs and the number of inputs and outputs cannot satisfy either Equation (3) or Equation (4), the dual form of DEA model must be used to solve the problem (Azar and Gholamrezaei, 2006).

$$\text{Number of DMUs} \ge 3 \times (\text{Number of inputs} + \text{Number of outputs}) \qquad (3)$$

$$\text{Number of DMUs} \ge 2 \times (\text{Number of inputs}) \times (\text{Number of outputs}) \qquad (4)$$

The dual form of Equation (2) is shown in Equation (5). This model not only returns more accurate results, but also provides the dual variables of objective improvement for each inefficient DMU as well as the suitable model of efficient units for the respective DMUs.

$\text{Min } Z_p = \theta$

St:

$\sum_{j=1}^{n} \lambda_j y_{rj} \geq y_{rp}$,r = 1,2,…,s

$\sum_{j=1}^{n} \lambda_j x_{ij} \leq \theta x_{ip}$,I = 1,2,…,k (5)

$\lambda_j \geq 0$,j = 1,2,…,n

θ : unconstrained in sign

When we want to rank and prioritize the units based on their efficiency scores, we need to use Andersen-Petersen model, which is a technique for rating efficient units. This model allows an efficient unit to have a higher than 1 efficiency score. To use this model, we need to remove the p-th constraint of the original model that was defined to determine the efficiency of unit P. Equation (6) shows the final form of Andersen-Petersen model (Azar et al, 2007).

$W_p = \text{Max} \sum_{r=1}^{s} v_r y_{rp}$

St:

$\sum_{i=1}^{k} u_i x_{ip} = 1$

و,j = 1,2,…,n $\sum_{r=1}^{s} v_r y_{rj} - \sum_{i=1}^{k} u_i x_{ij} \leq 0 \quad j \neq p$ (6)

,i = 1,2,…,k $u_i \geq 0$

,r = 1,2,…,s $v_r \geq 0$

The removal of mentioned constraint in the original model leads to the removal of corresponding variable in the dual form of the model. Equation (8) shows the final dual form of Andersen-Petersen model.

$\text{Min } Z_p = \theta$

St:

$\sum_{j=1, j\neq p}^{n} \lambda_j y_{rj} \geq y_{rp}$,r = 1,2,…,s

$\sum_{j=1, j\neq p}^{n} \lambda_j x_{ij} \leq \theta x_{ip}$,I = 1,2,…,k

$\lambda_j \geq 0$,j = 1,2,…,n

θ : unconstrained in sign

Another version of DEA is the BCC model, which was introduced in 1984 by Banker, Charnes and Cooper. This model is similar to CCR model, except that here returns to scale can be constant, decreasing or increasing. Equation (8) shows the input-oriented form of BCC model (Mirjalili et al, 2010; Azar and Zali, 2006; Banker et al, 1984). (7)

$$\begin{aligned}
&Min\,\theta \\
&s.t: \sum_{j=1}^{n} \lambda_j x_{ij} \leq \theta x_{i0} \quad , i = 1,2,...,m \\
&\sum_{j=1}^{n} \lambda_j y_{rj} \geq y_{r0} \quad , r = 1,2,...,s \\
&\sum_{j=1}^{n} \lambda_j = 1 \quad , j = 1,2,...,n \\
&\lambda_j \geq 0
\end{aligned} \tag{8}$$

Equation (8) is the envelopment form of CCR model plus constraint $\sum_{j=1}^{n} \lambda_j = 1$. Equation (9) shows the input-oriented dual envelopment form of BCC model (Azar and Zali, 2006. Banker et al, 1984).

$$\begin{aligned} & Max\, u^t y_0 - u_0 \\ & \quad s.t: v^t x_0 = 1 \\ & \qquad u^t y_j - v^t x_j - u_0 \le 0 \\ & \qquad u \ge 0, v \ge 0 \quad , j = 1, 2, \ldots, n \end{aligned} \tag{9}$$

Equation (9) is known as the multiplicative input-oriented BCC model. Given that $v^t x_0 = 1$, the objective function of the above model can be expressed as Equation (10). This model is known as the fractional input-oriented BCC model (Azar and Zali, 2006. Banker et al, 1984):

$$\begin{aligned} & Max \frac{u^t y_0 - u_0}{v^t x_0} \\ & \quad s.t: \frac{u^t y_j - u_0}{v^t x_j} \le 1 \\ & \qquad v \ge 0, u \ge 0 \end{aligned} \tag{10}$$

u_0 : unconstrained in sign:

1- If $(u_0 \succ 0)$, then returns to scale will be decreasing.
2- If $(u_0 = 0)$, then returns to scale will be constant.
3- If $(u_0 \prec 0)$, then returns to scale will be increasing.

Similarly, output-oriented BCC in its envelopment, multiplicative and fractional form will be as Equations (11), (12) and (13) (Banker et al, 1984):

$$\begin{aligned} & Max\, \varphi \\ & \quad s.t: X\lambda \le x_0 \\ & \qquad Y\lambda \ge \varphi y_0 \\ & \qquad \sum \lambda = 1 \\ & \qquad \lambda \ge 0 \\ & \qquad \theta : unrestricted\ in\ sign \end{aligned} \tag{11}$$

$$\begin{aligned} & Min\, z = v^t x_0 - v_0 \\ & \quad s.t: u^t y_0 = 1 \\ & \qquad v^t X - u^t Y - v_0 e \le 0 \\ & \qquad u \ge 0, v \ge 0 \\ & \qquad \theta : unrestricted\ in\ sign \end{aligned} \tag{12}$$

$$\begin{aligned} & Min \frac{v^t x_0 - v_0}{u^t y_0} \\ & \quad s.t: \frac{v^t x_j - v_0}{u^t y_j} \ge 1 \\ & \qquad v \ge 0, u \ge 0 \\ & \qquad \theta : unrestricted\ in\ sign \end{aligned} \tag{13}$$

3.1. Modeling variables

A geothermal energy source is a combination of three fundamental factors: a natural heat sources such as a mass of magma, geothermal fluid (usually water), and a geothermal reservoir near the heat source than can partially hold the geothermal fluid (SUNA, 2015). Different input and outputs are as followings:

- The number of geothermal springs
- The number of geothermal fields
- The closest distance between the geothermal fields and the main roads
- The closest distance between the geothermal fields and the provincial capitals
- Total power generation capacity
- The number of provincial water resources
- The number of hydrogen-consuming industries in the province
- The distance of hydrogen-consuming industries from the provincial capital
- The availability of skilled labor in province
- Population of province
- The level of air pollution
- The level of precipitation
- Area of the province

4. Analysis

To study the feasibility and priority of different regions of Iran for producing hydrogen via geothermal power-assisted water electrolysis, 14 provinces were selected to be used as decision-making units of DEA method. For simplicity's sake, these decision-making units were denoted by the acronym "*DMU*" plus the index corresponding to the number of intended unit.

4.1. Data Envelopment Analysis method

After considering the number of variables and decision-making units and the uncertainty in the status of outputs with respect to variations in inputs, we used the dual form of DEA and variable returns to scale or BCC approach to model the problem. All DEA calculations were performed by DEA Solver software.
The results of Andersen-Petersen technique are shown in Table 1.

Table 1. Efficiency of DMUs (obtained through Andersen-Petersen technique)

	Province	Efficiency
1	Eastern Azarbaijan	1.9328
2	Hormozghan	1.7215
3	Boshehr	1.5777
4	Ardabil	1.3175
5	Mazandaran	1.2669
6	Western Azarbaijan	1.1970
7	Southern Khorasan	1.1600
8	Esfahan	1.1122
9	Fars	1.0784
10	Ghazvin	1.0366
11	Zanjan	1.0278
12	Khorasan Razavi	1.0247
13	Kerman	0.4283
14	Sistan-Balochestan	0.2335

As Table 1 shows, East-Azarbaijan with efficiency score of 1.932, Hormozgan with efficiency score of 1.721, and Bushehr with efficiency score of 1.577 are the top three DMUs in terms of efficiency. On the other hand, Kerman and Sistan-Baluchestan gained less-than-one efficiency scores, so they were ranked as the most inefficient units.

4.2. TOPSIS technique

In accordance with the procedures of TOPSIS technique, we first formed a decision matrix with respect to DMUs and their respective variables. After normalizing this matrix, we assigned a weight to each variable and calculated the normalized weighted matrix. We then calculated the values of positive and negative ideal solutions and the distance of each option to these points, and ultimately determined the closeness coefficient of each option. Table 2 shows the ranking of options based on calculated closeness coefficients. In results presented in Table 2, a higher closeness coefficient means that option is closer to the positive ideal solution thus farther away from the negative ideal solution.

Table 2. Ranking of the options based on their closeness coefficient

DMUs	Closeness Coefficient	Rank
Boshehr	0.8519	1
Hormozghan	0.6308	2
Esfahan	0.6223	3
Fars	0.6048	4
Eastern Azarbaijan	0.6046	5
Mazandaran	0.5812	6
Khorasan Razavi	0.5767	7
Zanjan	0.5759	8
Ghazvin	0.5753	9
Kerman	0.5733	10
Sistan-Balochestan	0.5687	11
Southern Khorasan	0.5578	12
Ardabil	0.5412	13
Western Azarbaijan	0.1423	14

4.3. VIKOR technique

In accordance with the procedures of VIKOR technique, after forming the initial decision matrix and specifying the weight of each criterion, we formed the weighted decision matrix. We then determined the positive and negative ideal points and calculated the benefit and cost of each alternative. Next, we calculated the Q of each alternative based on its cost and benefit while assuming a compromise weight of 0.5, and finally obtained the VIKOR ranking.
Table 3 shows the ranking of alternatives based on index Q. According to VIKOR ranking, Bushehr with the lowest Q is the best option and West-Azerbaijan with the highest Q is the worst.

Table 3. Ranking of the alternatives based on their Q

DMUs	Si	Ri	Q	Rank
Boshehr	0.2465	0.0680	0	1
Eastern Azarbaijan	0.3883	0.1566	0.3509	2
Hormozghan	0.3873	0.1790	0.3993	3
Esfahan	0.4369	0.1566	0.4040	4
Fars	0.4565	0.2014	0.5244	5
Mazandaran	0.4374	0.2238	0.5531	6
Ardabil	0.4859	0.2238	0.6060	7
Zanjan	0.5015	0.2238	0.6230	8
Ghazvin	0.5331	0.2238	0.6575	9
Khorasan Razavi	0.5460	0.2238	0.6716	10
Kerman	0.5668	0.2238	0.6943	11
Sistan-Balochestan	0.6050	0.2238	0.7360	12
Southern Khorasan	0.6537	0.2238	0.7891	13
Western Azarbaijan	0.7047	0.2939	1	14

Table 4 shows the results obtained through DEA, TOPSIS and VIKOR. East-Azarbaijan, which is ranked first by DEA, is ranked second by VIKOR and fifth by TOPSIS. Hormozgan is ranked second by both DEA and TOPSIS, but is ranked third by VIKOR. Bushehr, which which is ranked first by both VIKOR and TOPSIS, is third in DEA ranking. Kerman is 13th, 10th, and 11th and Sistan-Baluchestan is 14th, 11th, and 12th in DEA, TOPSIS, and VIKOR rankings respectively.

Table 4. Summarized ranking of alternatives based on DEA, TOPSIS, and VIKOR

DMUs	DEA		TOPSIS		VIKOR	
	Efficiency	Rank	Closeness Coefficient	Rank	Q	Rank
Eastern Azarbaijan	1.9328	1	0.6046	5	0.3509	2
Hormozghan	1.7215	2	0.6308	2	0.3993	3
Boshehr	1.5777	3	0.8519	1	0	1
Ardabil	1.3175	4	0.5412	13	0.606	7
Mazandaran	1.2669	5	0.5812	6	0.5531	6
Western Azarbaijan	1.197	6	0.1423	14	1	14
Southern Khorasan	1.16	7	0.5578	12	0.7891	13
Esfahan	1.1122	8	0.6223	3	0.404	4
Fars	1.0784	9	0.6048	4	0.5244	5
Ghazvin	1.0366	10	0.5735	9	0.6575	9
Zanjan	1.0278	11	0.5759	8	0.623	8
Khorasan Razavi	1.0247	12	0.5767	7	0.6716	10
Kerman	0.4283	13	0.5733	10	0.6943	11
Sistan-Balochestan	0.2335	14	0.5687	11	0.736	12

Examining the rank of each province in the rankings obtained by the three methods shows that there is not too much difference between the ranking of DEA and those of VIKOR and TOPSIS.

The obtained rankings are also shown in Figure 3. This figure, where DMUs are depicted based on their efficiencies according to DEA, VIKOR, and TOPSIS, shows that all three method recognize East-Azarbaijan and Hormozgan as the most efficient and Sistan-Baluchestan, and Kerman as the least efficient provinces for hydrogen production via geothermal energy-assisted water electrolysis.

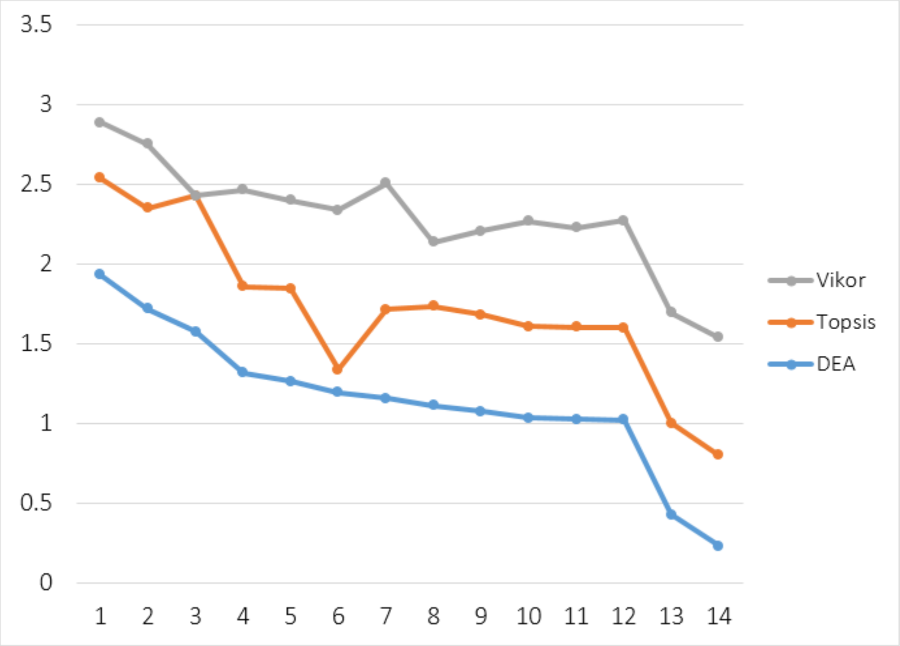

Figure 3. The stacked bar chart comparing the results of three models of problem solving

5. Conclusion

The aim of this paper was to examine the potential of different parts of Iran for producing hydrogen via a water electrolyzer that would use the electricity generated from a geothermal source. This goal was pursued by studying the feasibility and priority of 14 provinces based on a series of important decision-making variables.

Feasibility and potential of hydrogen production from geothermal source can be studied through 13 measurable factors. These factors include the number of geothermal springs and geothermal fields, the closest distance of geothermal fields from the main roads the provincial capitals, the total producible geothermal power, the number of provincial water resources, the number of hydrogen-consuming industries in each province and their distance from provincial capitals, availability of skilled labor, population of province, levels of air pollution and precipitation, and total area of the province.

As mentioned before, the objective was to assess and rank 14 Iranian provinces based on the above-mentioned variables to determine their suitability for the production of hydrogen through geothermal power assisted water electrolysis. This objective was pursued through the use of data envelopment analysis (DEA), which is a well-known multi-criteria decision-making method. In accordance with this method, the decision-making units (provinces) were first examined in terms of their efficiency, and then Andersen-Petersen technique was used to obtain the final ranking of units.

14 provinces examined in this study included: East-Azerbaijan, West-Azerbaijan, Ardebil, Isfahan, Bushehr, southern-Khorasan, Khorasan-Razavi, Zanjan, Sistan-Baluchestan, Fars, Qazvin, Kerman, and Hormozgan. These provinces were selected as DMUs because they possessed the minimum geothermal potential necessary to generate geothermal electricity required to produce hydrogen. After analysis and prioritization of all studied provinces, East-Azarbaijan was discovered to be the best option for hydrogen production via geothermal power-assisted water electrolysis. These results also showed that Kerman and Sistan-Baluchistan are inefficient in this regard and therefore unsuitable for this purpose.

A sensitivity analysis, which was conducted to determine the effect of each variable on efficiency of each province, showed that the level of precipitation, the number of hydrogen-consuming industries, population, and the number of geothermal springs have the greatest impacts on the efficiency of a province.

In the end, two methods, TOPSIS and VIKOR, were used to assess the validity of conducted analysis. Comparing the results of these two methods with those obtained by DEA showed that the rankings obtained by these three methods were similar to a great extent and only had minor differences. The closer examination showed that except few cases, all provinces had similar or very close ranking in all three methods.

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