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Location optimization of agricultural residues-based biomass plant using Z-number DEA

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Abstract

Co-firing biomass plants are of extensive demand due to utilization of both agricultural residues (main) and natural gas (stand-by). Researchers have shown that one strategic decision in establishment of agricultural residues based plants, is location optimization problem. Moreover, mismatch between agricultural lands and biomass plants can lead to high transportation costs and related carbon dioxide emissions. Standard indicators are considered and used for the stated multi-objective mathematical problem. This article presents a novel approach based on Z-number data envelopment analysis (DEA) model to handle severe uncertainty associated with actual data. The multi-objective mathematical model considers environmental, economic and social aspects of biomass plants. Moreover, fuzzy DEA model is utilized to verify and validate the results of Z-number DEA model through 30 independent experiments. The obtained results indicate that “accessibility to water”, “population”, “cost of land”, and “unemployment rate” are the most significant factors in location optimization of co-firing power plants. The obtained results also indicate that “Ilam”, “Semnan”, “Kohgiluyeh and Boyer-ahmad”, “South Khorasan”, and “Chaharmahal and Bakhttiari” are the optimum locations. This is the first unique approach for location optimization of co-firing plants based on combined agricultural residues and natural gas under uncertainty. Second, a unique fuzzy mathematical optimization approach is presented. Third, it is a practical approach for biomass power plants.

Keywords: Co-Firing biomass plants, location optimization; Z-Number Data Envelopment Analysis (DEA), environmental, economic and social indicators, Fuzzy Data Envelopment Analysis (FDEA), perturbation analysis

1- Introduction

Progressive consumption of fossil fuels in industrial plants and transportation sections have turned Iran into one the most infected countries to environmental issues. Iran’s dependency on oil and natural gas as a main sources of energy for refineries, chemical and petchochemical plants, and power generations plays an important role in air pollution and climate change of the region (Cobuloglu and Büyüktahtakın, 2014).

Apart from the strategic and economic debate, Iran requires a new sources of renewable energy for decreasing the emission of green house gases (GHGs) and air pollution problems. Although seeking for renewable sources of energy is a relatively new issue to developing countries, developed countries have started to consider the renewable sources of energy as potential long term sources in 1980s.

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Thirty years later, renewable energy accounts for eight percent of energy supply in United States of America. Biomass is a renewable energy source derived from organic matters such as wood or agricultrural residues. Its make up 4.8 percent of total United states energy consumption. Various technologies are introduced for obtaining energy from biomass in past decades. Using wood residues as a source of energy goes back to World War II. This technology was not efficient and leaded to deforestation. In recent years, biofuel generations have attracted many researchers in the field of biomass. Although the biofuel generations based on corn, sugarcrane and beets were successful, it had a negative impact on supply and demand of food, and lead to increase of prices. Burning of biomass is also an simple approach to obtain energy from biomass. This technology is used to generate heat and eletricity in United states, some European and Asian countries. The agricultural crop residues including wheat straw, corn stover, and oats are the main sources of biomass to generate electricity and heat (Shen et al., 2015). Various types of biomass plants are introduced in the last decades. Co-firing technology has proved to be the cheapest and most popular approach for power generations in recent years. This technology uses biomass with primary fossil fuel. The main advantage of this technology is constant fuel for seasons that agrucultural residues are not available (Basu et al., 2011). Although the investment and operation costs are relatively low, there are some disadvantages regarding co-firing plants. Since the density of agricultural residues is realtively low, the number of transportations will be high in compare to fossil fuels such as coal. Therefore, the carbon dioxide emissions can increase dramatically, if the location of the co-firing biomass plant is not near the feedstock. One of the main milestones for Iran to reduce oil and natural gas dependency is strategic planning for biomass plants for future. As explained, agricultural residues can be a smart choice considering the climate, geographical and agricultural conditions of Iran. One of the first strategic decisions that should be made in this regard, is location of the co-firing biomass plant for eletricity generation. There are various aspects to consider for location optimization of a biomass plant including economic, social and environmental.

1-1- Economic aspects

The considered economic criteria for biomass plant location are presented as follows (Moller, 2005; Bueyuektahtakin and Cobuloglu, 2014; Dong et al., 2015):

- Rate of Economic participation: measure the ratio of participating of this kind of biomass in macro level of economic throughout a country. In other words, how much biomass can help to economic growth within a particular region.
- Railroads accessibility: accessibility to rairoads for transportation section of supply chain network can be considered as an appropriate criteria.
- Cost of land: The cash value of land for constructing factories and cultivation areas; total cost is a critical factor for decision making problems.

1-2- Social aspects

The considered social criteria for biomass plant location are presented as follows (Bueyuektahtakin and Cobuloglu, 2014):

- Population: one of the most important macroeconomic factors in location optimization is population density. It affects labor accessibility, economic justification, and future developments planning of the government for producing required energy.
- Unemployment Rate: the unemployment rate is the share of the labor force that is jobless, expressed as a percentage.

1-3- Environmental aspects

Two criteria are associated with the environmental aspects of biomass production (Hartman et al., 2011; Shukla et al., 2013):

- Water accessibility: accessibility to water resources for irrigation and cultivation of lands in order to grow biomasses.

- Air pollution index: air pollution index (API) is a generalized index which describes the air quality; the range of 0-50 refers to clean air, 50-100 describes the healthy air, 100-200 refers to unhealthy for sensitive groups, 200-300 describes very unhealthy, and finally more than 300 describes very dangerous air situation for anyone (Murena, 2004).
- Production rate of wheat (ton per year): this index presents the wheat production rate in each province per year. Researchers have shown that each ton of wheat residues are produced with approximately 20 bushels of wheat (544.3104 kilogram).
- Production rate of corn: this index presents the corn production rate in each province per year. Researchers have shown that each ton of corn residues are produced with approximately 40 bushels of corn (1088.620 kilogram).
- Production rate of barley: this index presents the barley production rate in each province per year. Researchers have shown that each ton of barley residues are produced with approximately 40 bushels of barley (870.896 kilogram).

2- Literature review

The significant impacts of fossil fuels on climate change, and need for renewable energy sources have attracted many researchers in past decades. In this regard, many studies have addressed strategic and operational decisions in biomass logistics and location problem (Bai et al., 2011). The most important decisions investigated by the researchers regarding biomass plants are classified as follows:

2-1- Location problem

Location problem is one of the most important decisions in establishment of biomass plants. The long distances between plant, feedstock and demand can lead to high transportation costs and environmental impacts. Leduc et al. (2010) optimized location of methanol-based biomass plant in Sweden using a dynamic approach. Zhang et al. (2011) proposed a two stage methodology based on multi-attribute decision making (MADM) and mathematical programming for location optimization of wood residues based biomass plant. Vera et al. (2010) developed a honey bee foraging approach for location and size optimization of olive tree residues based biomass plant, in order to maximize the profit. Cebi et al. (2016) proposed an approach based on AHP and fuzzy information axiom for location optimization of agricultural residues based biomass plant in Turkey. The presented model considered both quantitative and qualitative criteria for determining the optimal location. Bargos et al. (2016) proposed a binary linear programming model for optimizing the location of sugarcane based ethanol mills in Brazil. A comprehensive multi-criteria assessment process is considered in GIS environments in order to identify the appropriate regions for building biomass mills by (Perpiña et al., 2013). Bojic et al. (2018) proposed a p median based mathematical model for locating bioethanol plant in Serbia. Davtalab and Alesheikh (2018) developed an integrated framework based on fuzzy analytic network process (FANP) and weighted linear combination to optimize the location of biomass power plant in Iran. Tan et al. (2018) presented a biomass power plant location optimization model by taking into account the geographical locations of the biomass and biomass availability in Malaysia.

2-2-Biomass crop types

Selection of optimum biomass crop type is one of the most significant decisions in establishment of biomass plants. The main factors in selection of optimum biomass crop are price, supply, and combustion properties (McKendry, 2002). One of the most comprehensive studies in this field is presented by (Cobuloglu and Büyüktahtakın, 2015). They proposed a stochastic multi-criteria decision making method based on stochastic AHP for biomass crop selection. They considered three main criteria including economic, environmental, and social aspects. The obtained results indicate that wheat and corn are best crops based on economic aspects, while emphasizing on environmental aspects leads to switch grass. Determining the optimal crop type is a multi-disciplinary problem. The combustion properties of each crop type can affect its efficiency in energy generation process. Discussion on this issue is beyond the scope of this article, however, more information are presented by (Sander, 1997).

2-3- Supply chain management (SCM)

Cambero et al. (2015) optimized the supply chain of forest residues for the production of bioenergy and biofuels by considering multi-period mixed integer linear programming model. The strategic design of biodiesel supply chain network in Iran is considered by data envelopment analysis (DEA) and mathematical programming techniques by (Babazadeh et al., 2015). Zhang et al. (2013) presented a mixed integer linear programming (MILP) model which integrates all the logistics decisions and supply chain for switch grass biomass plant. A stochastic mixed integer linear programming model is presented to plan optimal and appropriate hybrid generation bioethanol supply chain (HGBSC) by using renewable source called corn (Gonela et al., 2015). The strategic planning of an integrated biofuel supply chains (IBSC) presented in order to decrease the total annualized cost and total life cycle GHG (greenhouse gas) emissions as economic and environmental impacts respectively (Ivanov and Stoyanov, 2016). Tong et al. (2014) developed a multi-period MILP model for the design and planning of an advanced hydrocarbon biofuel supply chain by considering three types of biomass including crop residues (corn), energy crops (miscanthus), and wood residues (forest residues). Maheshwari et al. (2017) optimized the biofuel supply chain by taking into account the several potential disruptions. Chávez et al. (2018) optimized a biofuel supply chain from agricultural wastes using a multiple objective mixed integer linear programming model. Bairamzadeh et al. (2018) investigated different types of uncertainty in biofuel supply chain and proposed a robust approach to optimize the network design and planning of biofuel supply chain. Asadi et al. (2018) developed a bi-objective mathematical model to optimize biofuel production from algae by taking into account the location, inventory and routing decisions.

This paper determines the optimal location of co-firing biomass plants based on agricultural residues and natural gas in Iran for power generation. The presented algorithm is based on Z-number DEA and FDEA model and considers economic, environmental, and social aspects as well. To the best of our knowledge, this is the first approach for location optimization of co-firing plants based on combined agricultural residues and natural gas under uncertainty. Second, a unique fuzzy mathematical optimization approach is presented. Third, it is a practical approach for biomass power plants. The significant features of the presented study versus previous studies are indicated in Table 1.

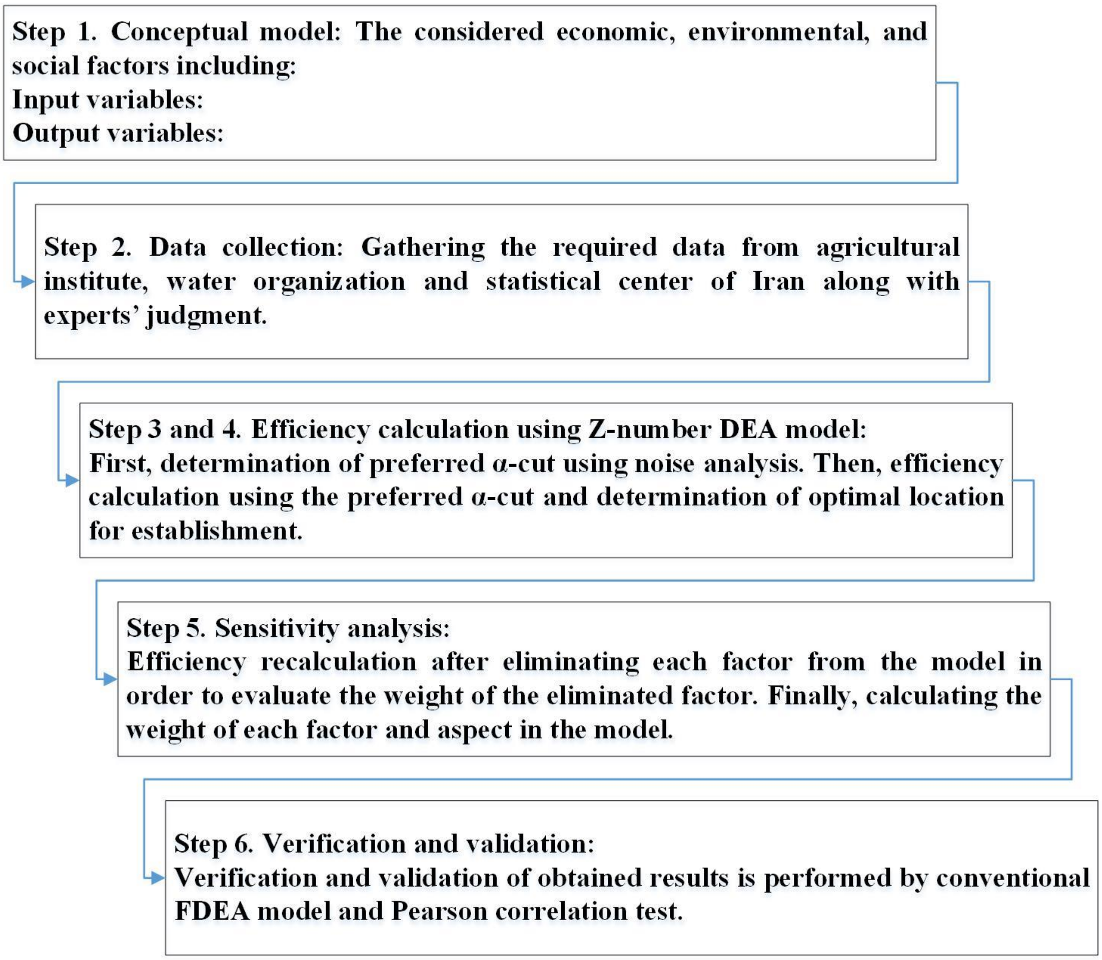
The plan for the remainder of the paper is as follows. Section 2 presents a description of the proposed methodology. Implementation of the algorithm on a real-world case study is explained in section 3. Section 4 provides the results obtained together with some fruitful analyses on them. Lastly, Section 5 is dedicated to concluding remarks and directions for future research.

Table 1. Significant features of these studies and their relevant different aspects

Study	**Solution Method**	**Economic aspect**	**Social impact**	**Environmental impact**
(Bai et al., 2011)	Linear programming relaxation			✓
(Zhou et al., 2012)	TOPSIS	✓		✓
Van Dael et al. (2012)	Macro screening	✓	✓	
(Perpiña et al., 2013)	MCA-GIS approach		✓	✓
(Zhang et al., 2013)	DEA,UDEA	✓	✓	
(Azadeh et al., 2014)	Fuzzy DEA,PCA,NT		✓	✓
(Tong et al., 2014)	Fuzzy possibilistic programming		✓	
(Cobuloglu and Büyüktahtakın, 2014)	Mixed-integer programming model	✓	✓	✓
(Cambero et al., 2015)	Multi-period mixed integer linear programming			✓
(Babazadeh et al., 2015)	DEA,UDEA	✓	✓	✓
(Cobuloglu and Büyüktahtakın, 2015)	AHP	✓	✓	✓
(Gonela et al., 2015)	Mixed-integer linear programming	✓		✓
(Heydari and Askarzadeh, 2016)	Hybrid system	✓	✓	✓
(Ivanov and Stoyanov, 2016)	Mixed-integer linear programming	✓		✓
(d'Amore and Bezzo, 2016)	Mixed-integer linear programming			✓
(Bargos et al., 2016)	Binary-linear programming			✓
(Babazadeh et al., 2016)	Unified fuzzy DEA model		✓	✓
(Maheshwari et al., 2017)	Mathematical programming and simulation optimization	✓		✓
(Asadi et al., 2018)	Bi-objective mathematical programming	✓		✓
(Bairamzadeh et al., 2018)	Mathematical programming and robust optimization	✓		✓
(Chávez et al., 2018)	Mixed-integer linear programming	✓		✓
This study	Z-number DEA and FDEA model	✓	✓	✓

2-Methodology

This study proposes an integrated approach based on Z-number DEA for optimizing co-firing biomass plant based on agricultural residues and natural gas location problem. In this regard, thirty alternative locations all over the country are considered in the algorithm and evaluated as the case study. Conventional DEA models have been used for location problems in the past decades by considering crisp data. Since the uncertainty is an inseparable part of real world problems, researchers proposed FDEA models for efficiency frontier analysis. Z-number DEA is a one step forward considering uncertainty in problems optimization. This model considers the expert's reliability along with fuzzy concept for efficiency frontier analysis. Z-number DEA model can be converted into the conventional FDEA by considering confident reliability for experts (Azadeh and Kokabi, 2016). Implementation of Z-number DEA helps us to combine the obtained quantitative data with obtained qualitative data from experts which leads to more precision. The structure of the presented approach is demonstrated in figure 1.



Step 1. Conceptual model: The considered economic, environmental, and social factors including:
Input variables:
Output variables:

Step 2. Data collection: Gathering the required data from agricultural institute, water organization and statistical center of Iran along with experts' judgment.

Step 3 and 4. Efficiency calculation using Z-number DEA model:
First, determination of preferred α-cut using noise analysis. Then, efficiency calculation using the preferred α-cut and determination of optimal location for establishment.

Step 5. Sensitivity analysis:
Efficiency recalculation after eliminating each factor from the model in order to evaluate the weight of the eliminated factor. Finally, calculating the weight of each factor and aspect in the model.

Step 6. Verification and validation:
Verification and validation of obtained results is performed by conventional FDEA model and Pearson correlation test.

Fig 1. Schematic view of the proposed algorithm

Step 1. *Conceptual model*

This study considers thirty alternative locations for co-firing biomass plant based on agricultural residues and natural gas in Iran as decision making units (DMUs). First, relevant effective factors to economic, social, and environmental aspects should be determined for biomass plant location problem. The identified factors which form the conceptual model of the presented approach are determined based on literature review and experts' judgments. After identification of effective factors, it is time to determine the input and output variables of the model. When increase in value of a factor caused decrease desirability, it is concluded that this factor belongs to input variables set. Rest of the identified factors should be considered as output variables in the conceptual model. The designed conceptual model of the current study is composed of three input variables including population, air pollution index, and cost of land, while the output variables are production rate of wheat, corn, and barley along with accessibility to water, railroads accessibility, unemployment rate, and rate of economic participation of the province. The population of region is considered as input variable due to the macroeconomic policies for the development of disadvantages regions and population decentralization in Iran. Therefore, increase the value of this factor decreases the desirability. This analysis implies for the rest of the considered factors. There are some other effective factors such as electricity-access which are not considered in the model due to availability in all of considered alternatives.

Step 2. *Data collection*

The required data are gathered from agricultural institute, water organization and statistical center of Iran along with experts' judgment. The gathered historical data are then analyzed by the help of organizations' experts to assess reliability and possible noises in the data. Collection of required data lasted about two months. Appendix I present the collected raw data.

Step 3. *Efficiency frontier analysis using Z-number DEA*

In this study, Z-number DEA model is utilized in order to evaluate the candidate regions for establishment of co-firing biomass plants based on agricultural residues in Iran.

Data envelopment analysis (DEA) is a conventional method for efficiency frontier analysis based on crisp data. However, in many real world problems, the related data are vague and highly uncertain. In these cases, experts' knowledge and reliability regarding collected quantitative data is very applicable. Z-number DEA model is designed based on fuzzy DEA model by considering the experts' reliability. Therefore, when the experts are confident about the variables values, Z-number DEA model can be converted into FDEA model (Azadeh and Kokabi, 2016). The concept of Z-numbers introduced by (Zadeh, 2011). Z-numbers related to variable X are defined based on a pair values such as (A, B). Where A is a fuzzy subset of the variable X, while B represents the reliability of the experts regarding the value of A. B can be represented by various concepts such as probability or possibility or sureness. Since A is a fuzzy subset of X, there should be a membership function for variable X. This membership function is usually considered triangular due to both computational simplicity and descriptive power (Aleksić et al., 2013). The reliability of the information is of great importance in planning and decision making. In order to consider the reliability of collected data in decision making analysis, Azadeh and Kokabi (2016) proposed a novel Z-number DEA model.

Suppose there are m input variables and s output variables regarding n DMUs. Both input and output variables are supposed to be Z-number for the DMU_i as presented in Equation (1) and (2), respectively.

$$\widetilde{Zx}_{ji} = \left(\widetilde{Ax}_{ji}, \widetilde{Bx}_{ji}\right) \qquad j = 1,2,\dots,m \tag{1}$$
$$\widetilde{Zy}_{ri} = \left(\widetilde{Ay}_{ri}, \widetilde{By}_{ri}\right) \qquad r = 1,2,\dots,s \tag{2}$$

Where $\widetilde{Bx}_{ji}$ and $\widetilde{By}_{ri}$ represent the restriction of certainty on the $\widetilde{Ax}_{ji}$ and $\widetilde{Ay}_{ri}$, respectively. The primal and dual of CCR model based on Z-numbers are presented in equations (3) and (4), respectively.

Indices	
i	Indices of DMUs ($i = 1, 2, \dots, 30$)
j	Indices of inputs ($j = 1, 2, 3$)
r	Input of outputs ($r = 1, 2, \dots, 7$)
n	Number of DMUs ($n = 30$)
m	Number of inputs ($m = 3$)
s	Number of outputs ($s = 7$)
DMU_i	The *i*th DMU
DMU_0	The target of DMU ($n = 0$)
Parameters	
x_{ji}	Value of input *j* related to DMU *i*
y_{ri}	Value of output *r* related to DMU *i*
v_j	Factor weight of input *j*
u_r	Factor weight of output *r*
$\widetilde{Zx}_{ji}$	Z-number value of input *i* related to DMU *i*
$\widetilde{Ax}_{ji}$	Fuzzy value of input *j* related to DMU *i*
$\widetilde{Bx}_{ji}$	Fuzzy reliability value of input *j* related to DMU *i*
$\widetilde{Zy}_{ri}$	Z-number value of output *r* related to DMU *i*

Variables	
λ_i	Weight variables for calculating the efficiencies of DMUs
θ_0	Objective efficiency of the model

$$
\begin{aligned}
&Min\ \theta_0 \\
&s.t \\
&\sum_{i=1}^{30} \lambda_i\ \widetilde{Zx}_{ji} \le \theta_0 \widetilde{Zx}_{j0} && j = 1, \dots, 3 \\
&\sum_{i=1}^{30} \lambda_i\ \widetilde{Zy}_{ri} \ge \widetilde{Zy}_{r0} && r = 1, \dots, 7 \\
&\lambda_i \ge 0 && i = 1, \dots, 30
\end{aligned}
\tag{3}
$$

$$
\begin{aligned}
&Max \quad \theta_0 = \sum_{r=1}^{7} u_r\, \widetilde{Zy}_{r0} = 1 \\
&s.t \quad \sum_{j=1}^{3} v_j\, \widetilde{Zx}_{j0} = 1 \\
&\sum_{r=1}^{7} u_r\, \widetilde{Zy}_{ri} - \sum_{j=1}^{3} v_j\, \widetilde{Zx}_{ji} \le 0, && i = 1, 2, \dots, 30 \\
&u_r, v_j \ge 0, && r = 1, 2, \dots, 7;\ j = 1, \dots, 3
\end{aligned}
\tag{4}
$$

As can be seen, the presented models in equations (3) and (4) are not linear. In order to linearize the models, the second part of each Z-number is added to the first part and the models are converted into weighted fuzzy DEA models. In the next step, the weighted fuzzy DEA models are converted to regular fuzzy numbers. Finally, the primal and dual linear Z-number CCR DEA models are presented in equations (5) and (6), respectively.

$$
\begin{aligned}
&MAX\ \theta_p = \sum_{r=1}^{7} \bar{y}_{rp} \\
&S.t. \\
&\sum_{j=1}^{3} \bar{x}_{jp} = 1 \\
&\sum_{r=1}^{7} \bar{y}_{ri} - \sum_{j=1}^{3} \bar{x}_{ji} \le 0 && i = 1, 2, \dots, 30 \\
&v_j\left(\alpha x_{ji}^{m} + (1-\alpha) x_{ji}^{l}\right) \le \bar{x}_{ji} \le v_j\left(\alpha x_{ji}^{m} + (1-\alpha) x_{ji}^{u}\right) && i = 1, \dots, 30;\ j = 1, \dots, 3 \\
&u_r\left(\alpha y_{ri}^{m} + (1-\alpha) y_{ri}^{l}\right) \le \bar{y}_{ri} \le u_r\left(\alpha y_{ri}^{m} + (1-\alpha) y_{ri}^{u}\right) && i = 1, \dots, 30;\ r = 1, \dots, 7 \\
&u_r, v_j \ge 0 && r = 1, \dots, 7;\ j = 1, \dots, 3
\end{aligned}
\tag{5}
$$

$$
\begin{aligned}
&Min\ \theta_p \\
&S.t. \\
&\theta_p\left(\alpha x_{jp}^{m} + (1-\alpha) x_{jp}^{l}\right) \ge \textstyle\sum_{i=1}^{30} \lambda_i\left(\alpha x_{ji}^{m} + (1-\alpha) x_{ji}^{u}\right) && j = 1, \dots, 3
\end{aligned}
\tag{6}
$$

$$\alpha y_{rp}^{m} + (1-\alpha) y_{rp}^{u} \leq \sum_{i=1}^{30} \lambda_i \left(\alpha y_{ri}^{m} + (1-\alpha) y_{ri}^{l} \right) \qquad r = 1,\ldots,7$$

$$\lambda_i \geq 0 \qquad i = 1,\ldots,30$$

It is important to note that there is a particular optimal solution for each α-cut. Therefore, the solution table is prepared based on various α in $[0, 1]$ (Azadeh and Kokabi, 2016). As mentioned previously, variable X has two fuzzy numbers. There are three interval numbers related to the scale of raw data gathered in step 2 including likely, usually, and sure as presented in table 2 (Azadeh and Kokabi, 2016). According to the concept of Z-number DEA model, it isn't an exact algorithm therefore the crisp data which are gathered should be demonstrated as fuzzy. As a first Step, the raw data have been deffuzied using equation (7) based on mean, minimum and maximum values. Deffuziation of gathered data are presented in appendix 2, respectively.

$$\left(mean - \frac{minimum}{2}, mean, mean + \frac{minimum}{2}\right) \tag{7}$$

Table 2. Classification of reliability values

Z= (A, B)	Reliability	Membership functions parameters
B	Sure	[0.8, 1, 1]
	Usually	[0.65.0.75.0.85]
	Likely	[0.5, 0.6, 0.7]

Step 4. *Determining preferred α-cut*

Since the Z-number DEA model is a fuzzy and non-deterministic model, therefore it should be tuned with a parameter namely α-cut. In this regard, we have to determine the optimum α-cut before evaluating the efficiency scores. Therefore, the Z-number DEA model is run based on the designed conceptual model for various α-cuts (0.01, 0.05, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 0.95, 0.99 and 1) using Auto-access software and the related efficiencies are collected. Different tools can be utilized in order to determine the optimum α- cut. Noise analysis is one of the recent methods for determining the optimum DEA model (preferred α-cut). In this method, thirty noises are created in collected data before efficiency calculation. In each noise, a random DMU value of one of factors is multiplied by 100. After obtaining the related efficiencies after each random noise, the Pearson correlation test is used for evaluating the impact of created noise on each α-cut. Finally, the α-cut which presents higher average Pearson correlation coefficient is selected as the preferred Z-number DEA model for efficiency frontier analysis.

Step 5. *Sensitivity analysis*

In order to calculate the weight of each considered factor, and to evaluate its current performance, sensitivity analysis is employed. In this regard, after obtaining the efficiency scores of the conceptual model, each factor is omitted from the model, and efficiency scores are recalculated. This process goes on until the related efficiency scores to nonexistence of each factor are obtained. Percentage of variation in efficiency which is computed by each factor demonstrates the weight of the factors. $\bar{\theta}$ is an average efficiency of a model which is composed of all considered factors without any elimination, and $\bar{\theta}_i$ is a related average efficiency to nonexistence of each factor. Equation (8) presents the weight percentage calculation of each factor.

$$w = \frac{\left|\bar{\theta} - \bar{\theta}_i\right|}{\sum_{i=1}^{n} \left|\bar{\theta} - \bar{\theta}_i\right|} \times 100 \tag{8}$$

Step 6. *Verification and validation*

As stated before, Z-number DEA model can be converted into the conventional FDEA by considering confident reliability for experts (Azadeh and Kokabi, 2016). Therefore, for verification and validation of obtained results, efficiency scores are recalculated using FDEA model. Since both models are fuzzy and non-deterministic DEA models, it is possible to evaluate the superiority and performance of Z-number DEA model for the agricultural residues based biomass plant location problem versus conventional FDEA.

Fuzzy DEA model is an appropriate model to assess and evaluate the efficiency of DMUs with vague and fuzzy input/output data (Azadeh et al., 2017). Here, we explain fuzzy DEA model proposed by Azadeh and Alem (2010) which have been presented in equation (9).

$$\begin{aligned}
&Max\ \theta = \sum_{r=1}^{7} u_r\, \widetilde{y_{p\iota}} \\
&\sum_{j=1}^{3} v_j\, \tilde{x}_{ji} = 1 \qquad\qquad i = 1, \ldots.,30 \\
&\sum_{r=1}^{7} u_r \widetilde{y_{r\iota}} - \sum_{j=1}^{3} v_j \widetilde{x_{J\iota}} \le 0 \qquad i = 1, \ldots,30 \\
&v_j\,, u_r \ge 0 \qquad\qquad j = 1,2,3;\ \ r = 1, \ldots,7
\end{aligned} \tag{9}$$

Different types of fuzzy function exist in fuzzy notion, but triangular functions are mostly utilized. Various α-cuts can be utilized in order to convert fuzzy models into fuzzy linear programming. The α-cut method which is utilized for converting FDEA model is presented in equation (10) (Azadeh et al., 2016).

$$\begin{aligned}
&\widetilde{X_{J\iota}}=\left(X_{ji}^{q}, X_{ji}^{l}, X_{ji}^{u}\right) \quad , \quad \widetilde{y_{J\iota}}=\left(y_{ji}^{q}, y_{ji}^{l}, y_{ji}^{u}\right) \\
&\max \omega = \sum_{r=1}^{7} u_r\left(\propto y_{ri}^{m} + (1-\propto) y_{ri}^{l}, \propto y_{ri}^{l} \propto y_{rp}^{m} + (1-\propto) y_{ri}^{u}\right) \\
&\sum_{j=1}^{3} v_j\left(\propto x_{ji}^{m} + (1-\propto) x_{ji}^{l}, \propto x_{ji}^{m} + (1-\propto) x_{ji}^{u}\right) = 1 \quad \mathrm{i} = 1, \ldots,30 \\
&\sum_{r=1}^{7} s_r\left(\propto y_{ri}^{m} + (1-\propto) y_{ri}^{l}, \propto y_{ri}^{m} + (1-\propto) y_{ri}^{u}\right) \\
&\qquad\qquad - \sum_{j=1}^{3} v_j\left(\propto x_{ji}^{m} + (1-\propto) x_{ji}^{l}, \propto x_{ji}^{m} + (1-\propto) x_{ji}^{u}\right) \le 0 \\
&v_j\,, u_r \ge 0 \qquad j = 1,2,3;\ r = 1, \ldots,7
\end{aligned} \tag{10}$$

In order to utilize FDEA model, the optimum α-cut must be specified similar to step 4. After determining an optimum α-cut for FDEA model, Spearman correlation test is applied to validate the obtained results of Z-number DEA model. The spearman test is used to evaluate the correlation between obtained ranks of DMUs using Z-number DEA model and FDEA model. In this study, statistical package Minitab Version 17 is used for implementation of statistical tests. If the obtained correlation coefficient between ranking of DMUs using Z-number DEA and FDEA model is more than 0.7, it is possible to claim that the obtained results of Z-number DEA are verified and validated.

3- Experiment

Iran is chosen as an exhibitive case study for the presented approach. Iran is among the list of polluted countries in the world and is highly depended on fossil fuels. Therefore, planning for renewable sources of energy is a strategic issue. Wheat, corn and barley are the main agricultural crops grown in Iran, which can be used for producing renewable energy in biomass plants (Dong et al., 2015). The required information on agricultural products is achieved from agricultural biotechnology institute of Iran. There are significant parameters in establishing a co-firing biomass plants including feedstock accessibility. However, Fars province is known as the highest wheat producer in the country, there are other aspects in determining the optimal location such as macroeconomic and environmental aspects. In this regard, thirty alternatives for establishment of co-firing biomass plant based on agricultural residues and natural gas in Iran are determined. Biomass attracts many hopes as a sustainable renewable energy alternative. Producing heat using agricultural residues has the potential to reduce oil dependency and emission of greenhouse gases. It also can boost rural development, and provide more job opportunities in agricultural and industrial sectors (Zhang et al., 2011).

4-Result and discussion

This study presents an integrated approach for optimizing location problem of a co-firing biomass plant based on agricultural residues in Iran. Z-number DEA is utilized to evaluate and rank the alternatives based on considered factors (Yager, 2012). The obtained results of Z-number DEA model are validated and verified by fuzzy DEA model. The computational results based on the presented approach are presented as follows:

4-1- Efficiency calculation by Z-number DEA

The obtained efficiency scores of Z-number DEA model based on various α-cuts are presented in table 3 and table 4.

Table 3. The obtained efficiency scores of Z-number DEA model based on various α-cuts (0.01, 0.05, 0.1, 0.2, 0.3, 0.4, and 0.5)

Provinces	DMU	α=0.01	α=0.05	α=0.1	α=0.2	α=0.3	α=0.4	α=0.5
Ardabil	1	2.6764	2.5622	2.4284	2.1861	1.9727	1.7836	1.6155
East Azerbaijan	2	1.4951	1.4447	1.3847	1.2730	1.1629	1.0633	0.9730
West Azerbaijan	3	1.4432	1.4016	1.3512	1.2563	1.1682	1.0863	1.0100
Bushehr	4	3.1600	2.9911	2.7946	2.4443	2.1419	1.8792	1.6495
Chaharmahal and Bakhttiari	5	4.0598	3.7959	3.4942	2.9701	2.5315	2.1602	1.8427
Isfahan	6	1.3256	1.3013	1.2713	1.2130	1.1573	1.1066	1.0588
Fars	7	1.2728	1.2554	1.2412	1.2130	1.1850	1.1574	1.1298
Gilan	8	1.5644	1.5122	1.4497	1.3328	1.2258	1.1275	1.0380
Golestan	9	2.5013	2.4029	2.2867	2.0750	1.8844	1.7091	1.5546
Hamedan	10	1.7301	1.6827	1.6254	1.5186	1.4252	1.3366	1.2522
Hormozgan	11	1.9628	1.8882	1.7986	1.6306	1.4766	1.3352	1.2046
Ilam	12	15.2289	12.6430	10.3016	7.2720	5.4040	4.1424	3.2372
Kerman	13	2.8896	2.7124	2.5114	2.1656	1.8797	1.6400	1.4369
Kermanshah	14	2.0315	1.9709	1.8981	1.7620	1.6373	1.5229	1.4188
South Khorasan	15	7.3110	6.5249	5.7006	4.4306	3.5014	2.7954	2.2432
Razavi Khorasan	16	1.6324	1.5952	1.5506	1.4672	1.3909	1.3209	1.2565
Nourth Khorasan	17	4.0071	3.7321	3.4195	2.8805	2.4337	2.0583	1.7449
Khuzestan	18	2.5663	2.4640	2.3432	2.1216	1.9216	1.7436	1.5847
Kohgiluyeh and Boyer-ahmad	19	8.0163	7.1746	6.2944	4.9434	3.9588	3.2131	2.6314
Kurdistan	20	2.1128	2.0443	1.9623	1.8099	1.6720	1.5475	1.4369
Lorestan	21	3.3275	3.1507	2.9483	2.5954	2.2984	2.0464	1.8317
Markazi	22	2.2165	2.1449	2.0591	1.8993	1.7536	1.6204	1.4984
Mazandaran	23	2.5303	2.4275	2.3066	2.0875	1.8942	1.7227	1.5695
Qazvin	24	2.6608	2.5433	2.4046	2.1518	1.9276	1.7278	1.5491

Table 3. Continued

Provinces	DMU	α=0.01	α=0.05	α=0.1	α=0.2	α=0.3	α=0.4	α=0.5
Qom	25	2.7342	2.6113	2.4673	2.2079	1.9839	1.7930	1.6209
Semnan	26	9.5388	8.4309	7.2997	5.6218	4.4345	3.5518	2.8722
Sistan and Baluchestan	27	2.5831	2.4770	2.3518	2.1232	1.9201	1.7388	1.5764
Tehran	28	1.1227	1.1157	1.1073	1.0912	1.0763	1.0624	1.0495
Yazd	29	3.2353	3.0815	2.9011	2.5735	2.2851	2.0298	1.8026
Zanjan	30	2.9508	2.7853	2.5933	2.2524	1.9597	1.7066	1.4864

Table 4. The obtained efficiency scores using Z-number DEA model based on various α-cuts (0.6, 0.7, 0.8, 0.9, 0.95, 0.99, and 1)

Provinces	DMU	α=0.6	α=0.7	α=0.8	α=0.9	α=0.95	α=0.99	1
Ardabil	1	1.4653	1.3306	1.2093	1.0994	1.0484	1.0095	1.0000
East Azerbaijan	2	0.8964	0.8349	0.7791	0.7301	0.7088	0.7038	0.7042
West Azerbaijan	3	0.9381	0.8751	0.8266	0.7819	0.7637	0.7521	0.7498
Bushehr	4	1.4475	1.2692	1.1115	0.9711	0.9065	0.8618	0.8543
Chaharmahal and Bakhttiari	5	1.5690	1.3312	1.1886	1.0847	1.0402	1.0077	1.0000
Isfahan	6	1.0136	0.9708	0.9300	0.8915	0.8712	0.8541	0.8498
Fars	7	1.1024	1.0762	1.0508	1.0252	1.0126	1.0025	1.0000
Gilan	8	0.9706	0.9434	0.9381	0.9823	0.9932	0.9989	1.0000
Golestan	9	1.4177	1.2957	1.1866	1.0885	1.0431	1.0085	1.0000
Hamedan	10	1.1719	1.0953	1.0212	0.9520	0.9456	0.9617	0.9658
Hormozgan	11	1.0981	1.0277	0.9697	0.9277	0.9216	0.9161	0.9154
Ilam	12	2.5588	2.0336	1.6165	1.2785	1.1328	1.0255	1.0000
Kerman	13	1.2655	1.1219	0.9972	0.9136	0.8878	0.8797	0.8778
Kermanshah	14	1.3222	1.2584	1.1684	1.0950	1.0467	1.0092	1.0000
South Khorasan	15	1.8039	1.4571	1.2161	1.0466	0.9718	0.9213	0.9112
Razavi Khorasan	16	1.1971	1.1422	1.0896	1.0424	1.0207	1.0040	1.0000
Nourth Khorasan	17	1.4780	1.3003	1.1486	1.0472	1.0153	1.0013	1.0000
Khuzestan	18	1.4423	1.3143	1.1989	1.0946	1.0461	1.0090	1.0000
Kohgiluyeh and Boyer-ahmad	19	2.1673	1.7901	1.4789	1.2191	1.1050	1.0202	1.0000
Kurdistan	20	1.3367	1.2423	1.1533	1.0691	1.0325	1.0067	1.0000
Lorestan	21	1.6365	1.4490	1.2804	1.1317	1.0639	1.0125	1.0000
Markazi	22	1.3869	1.2869	1.1904	1.0932	1.0459	1.0090	1.0000
Mazandaran	23	1.4321	1.3081	1.1957	1.0935	1.0457	1.0090	1.0000
Qazvin	24	1.3887	1.2441	1.1123	0.9795	0.9287	0.8937	0.8856
Qom	25	1.4652	1.3238	1.1924	1.0320	0.9674	0.9243	0.9143
Semnan	26	2.3349	1.9011	1.5451	1.2682	1.1192	1.0229	1.0000
Sistan and Baluchestan	27	1.4303	1.2984	1.1806	1.0829	1.0402	1.0079	1.0000
Tehran	28	1.0377	1.0269	1.0170	1.0081	1.0039	1.0008	1.0000
Yazd	29	1.5995	1.4171	1.2482	1.1122	1.0538	1.0104	1.0000
Zanjan	30	1.2937	1.1242	0.9745	0.8417	0.7809	0.7384	0.7315

4-2- Determining optimum α-cut

As explained in step 4, noise test is employed for determining optimum α-cut. The obtained average correlation coefficients between original and manipulated data are presented in table 5. Figure 2 demonstrate the comparison results for various α-cuts. As you see, the optimal Z-number DEA model α-cut for the presented study is 0.01.

Table 6 presents the obtained ranks and efficiencies for each DMU using the determined optimum Z-number DEA model. The Z-number DEA results indicate that “Ilam” has the highest efficiency score among considered alternatives for establishment of agricultural residues based biomass plant. As demonstrated in figure 3, the second and third place goes to “Semnan” and “Kohgiluyeh and Boyer-ahmad”, respectively.

Table 5. Average correlation of thirty noisy data sets for considered α-cuts

α-cut	**average correlation**	**α-cut**	**Average correlation**
0.01	0.854	0.6	0.843
0.05	0.838	0.7	0.839
0.1	0.852	0.8	0.837
0.2	0.842	0.9	0.833
0.3	0.818	0.95	0.841
0.4	0.811	0.99	0.848
0.5	0.843	0.1	0.836

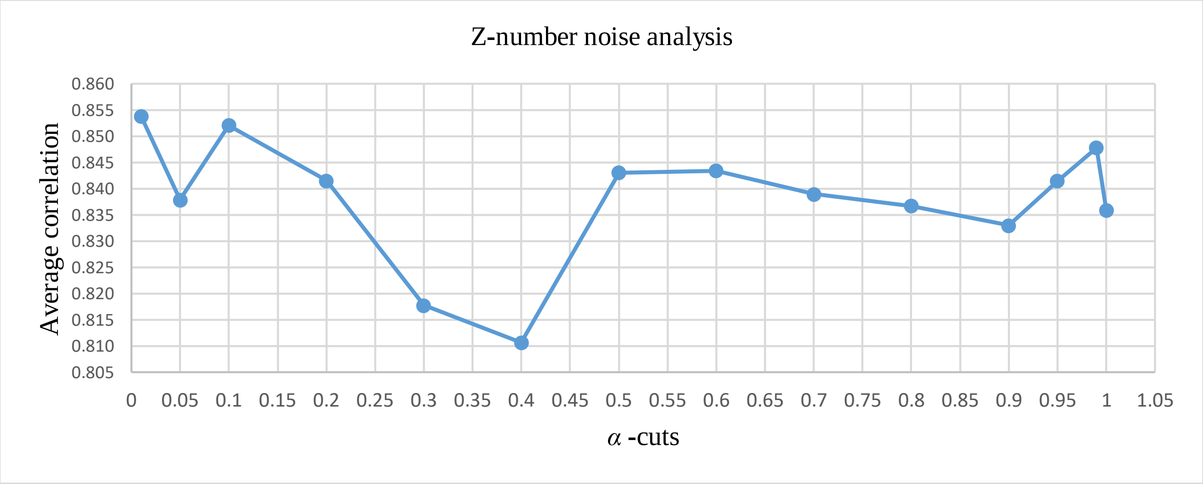


Fig 2. Comparison between obtained average correlations based on noise analysis for Z-number DEA model

Table 6. The ranking results of the optimum Z-number DEA model (α= 0.01)

Provinces	DMU	Efficiency	Rank	Provinces	DMU	Efficiency	Rank
Ardabil	1	2.676442	13	Razavi Khorasan	16	1.632425	24
East Azerbaijan	2	1.495054	26	Nourth Khorasan	17	4.007141	6
West Azerbaijan	3	1.443241	27	Khuzestan	18	2.566269	16
Bushehr	4	3.159975	9	Kohgiluyeh and Boyer-ahmad	19	8.01632	3
Chaharmahal and Bakhttiari	5	4.05984	5	Kurdistan	20	2.112803	20
Isfahan	6	1.325603	28	Lorestan	21	3.327451	7
Fars	7	1.27277	29	Markazi	22	2.216482	19
Gilan	8	1.564382	25	Mazandaran	23	2.530288	17
Golestan	9	2.501308	18	Qazvin	24	2.660821	14
Hamedan	10	1.730114	23	Qom	25	2.734158	11
Hormozgan	11	1.962783	22	Semnan	26	9.53879	2
Ilam	12	15.22891	1	Sistan and	27	2.583129	15

Table 6. Continued

Provinces	DMU	Efficiency	Rank	Provinces	DMU	Efficiency	Rank
				Baluchestan			
Kerman	13	2.88956	11	Tehran	28	1.122692	30
Kermanshah	14	2.031484	21	Yazd	29	3.235341	8
South Khorasan	15	7.310986	4	Zanjan	30	2.950787	10

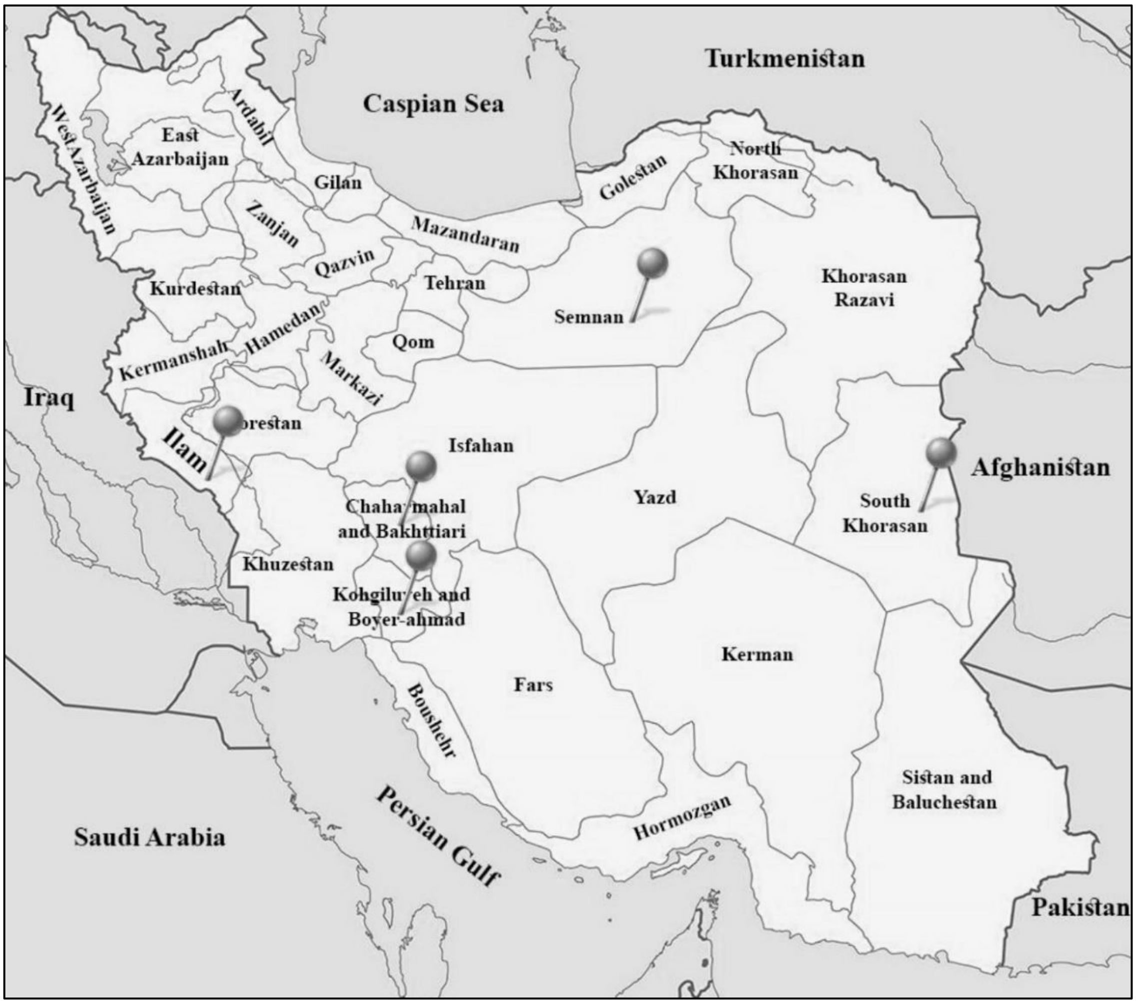


Fig 3. The five top alternatives for establishment of co-firing biomass plant

4-3- Sensitivity analysis

Sensitivity annalysis is performed according to step 5. Obtained results of the sensitivity analysis using optimum α-cut equals to 0.01 are presented in table 7.

Table 7. Results of sensitivity analysis for each factor in Z-number DEA model

DMU	Population	Air Pollution Index	Cost of Land	Rate of Economic Participation	Accessibility to Railroads	Unemployment Rate	Corn Production	Barley Production	Wheat Production	Water Accessibility
1	2.6048	2.6764	2.5748	2.2875	2.6581	2.5890	2.6764	2.6567	2.6764	2.5348
2	1.4951	1.4951	0.9724	1.3306	1.4951	1.3170	1.4951	1.4951	1.4637	1.2470
3	1.4432	1.4432	0.9066	1.3130	1.4139	1.4432	1.4432	1.3860	1.4432	1.1572
4	1.2812	3.1600	3.1600	2.5818	3.1600	2.7328	3.1600	3.1600	3.1600	1.8621
5	1.4538	4.0598	4.0598	3.3668	4.0598	3.0443	4.0598	4.0598	4.0598	3.0419
6	1.3256	1.3256	1.0046	1.2136	1.2845	1.3256	1.3256	1.2388	1.3256	1.0517
7	1.2728	1.2661	1.0588	1.2474	1.2107	1.2728	1.2728	1.2259	1.2346	1.2728
8	1.5644	1.5644	1.1359	1.0890	1.5644	1.4803	1.5644	1.5644	1.5644	1.4168
9	2.5013	2.5013	1.7735	1.9960	2.5013	2.3745	2.5013	2.5013	2.3929	2.4127
10	1.0903	1.7301	1.7301	1.7105	1.7301	1.7301	1.7301	1.6600	1.7301	1.4694
11	1.6644	1.9628	1.9628	1.8138	1.9628	1.7991	1.9579	1.9628	1.9628	1.6063
12	3.3250	15.2289	15.2289	12.5509	15.2289	13.7939	15.2130	15.2289	15.2289	11.3314
13	2.8896	2.8896	0.8508	2.7971	2.6022	2.4554	2.8896	2.8896	2.8896	2.7327
14	2.0315	2.0315	1.8717	1.8456	2.0315	2.0315	2.0273	1.9824	2.0315	1.9609
15	1.4122	7.3110	7.3110	6.0523	7.3110	6.1230	7.3110	7.3110	7.3110	5.6939
16	1.7797	1.6324	0.7405	1.5715	1.5484	1.6324	1.6324	1.2874	1.6324	1.5739
17	1.2320	4.0071	4.0071	3.1594	4.0071	3.4878	4.0071	3.9302	4.0071	3.2090
18	2.5663	2.5663	1.2567	2.4567	2.5663	2.4899	2.5521	2.5663	2.5663	2.4696
19	2.9288	8.0163	8.0163	7.1988	8.0163	5.7393	8.0149	8.0163	8.0163	6.1089
20	1.4466	2.1128	2.1128	2.0640	2.1128	2.1086	2.1128	2.1128	1.8807	1.7630
21	3.3275	3.3275	1.7060	3.1445	3.3222	3.1753	3.3275	3.2598	3.3275	3.1597
22	1.0476	2.2165	2.2165	2.1397	2.2165	2.2165	2.2165	2.1087	2.2165	1.6363
23	2.5303	2.5303	1.2182	2.2138	2.5303	2.3255	2.5303	2.5303	2.5303	2.2682
24	1.1017	2.6608	2.6608	2.3355	2.6608	2.4177	2.6608	2.5728	2.6608	1.9240
25	1.0122	2.7342	2.7342	2.6745	2.7342	2.3174	2.7342	2.6730	2.7342	1.6947
26	3.1473	9.5388	9.5388	9.5141	9.5388	8.4986	9.5388	9.5388	9.5388	7.2530
27	2.5831	2.5831	0.9673	2.4820	2.3436	2.0298	2.5831	2.5831	2.5831	2.3499
28	1.1227	1.1227	1.0470	1.1078	1.1227	1.0793	1.1227	1.1227	1.1227	0.5905
29	2.8429	3.2353	3.2353	3.2309	3.1844	2.7344	3.1893	3.2353	3.2353	2.5968
30	1.3522	2.9508	2.9508	2.4994	2.9508	2.4194	2.9508	2.9508	2.9508	1.8878

As explained in step 5, the difference between average efficiency of before and after factor's elimination presents the weight of each factor. The calculated weights for considered factors are presented in table 8 and figure 4. The obtained results indicate that "accessibility to water", "population", "cost of land", and "unemployment rate" are the most significant factors in location optimization of co-firing biomass plant based on agricultural residues and natural gas in Iran. As indicated in table 10, the weight of "air pollution index" is not significant in selection of the optimal location. This may be the result air pollution uniformity of many provinces in Iran. Therefore, this factor has just decreased the efficiency scores of polluted cities such as Tehran, Khuzestan, and Isfahan. It doesn't play an important role in comparing other alternatives. The weight of agricultural productions are not significant due to availability of required agricultural residues in most of provinces for the considered plant. Since, it is the first co-firing biomass plant in Iran, it doesn't have to compete for feedstock with any other plant. "Accessibility to Railroads" is not significant, too. This may be the result of low distances from feedstock to the plant.

Table 8. The calculated weights for considered factors

Factor	**Weight (%)**
Population	20.13295
Air Pollution Index	0.083282
Cost of Land	16.48559
Rate of Economic Participation	15.1281
Accessibility to Railroads	1.136794
Unemployment Rate	16.24408
Corn Production	0.120758
Barley Production	1.494905
Wheat Production	0.570479
Accessibility to Water	28.60306

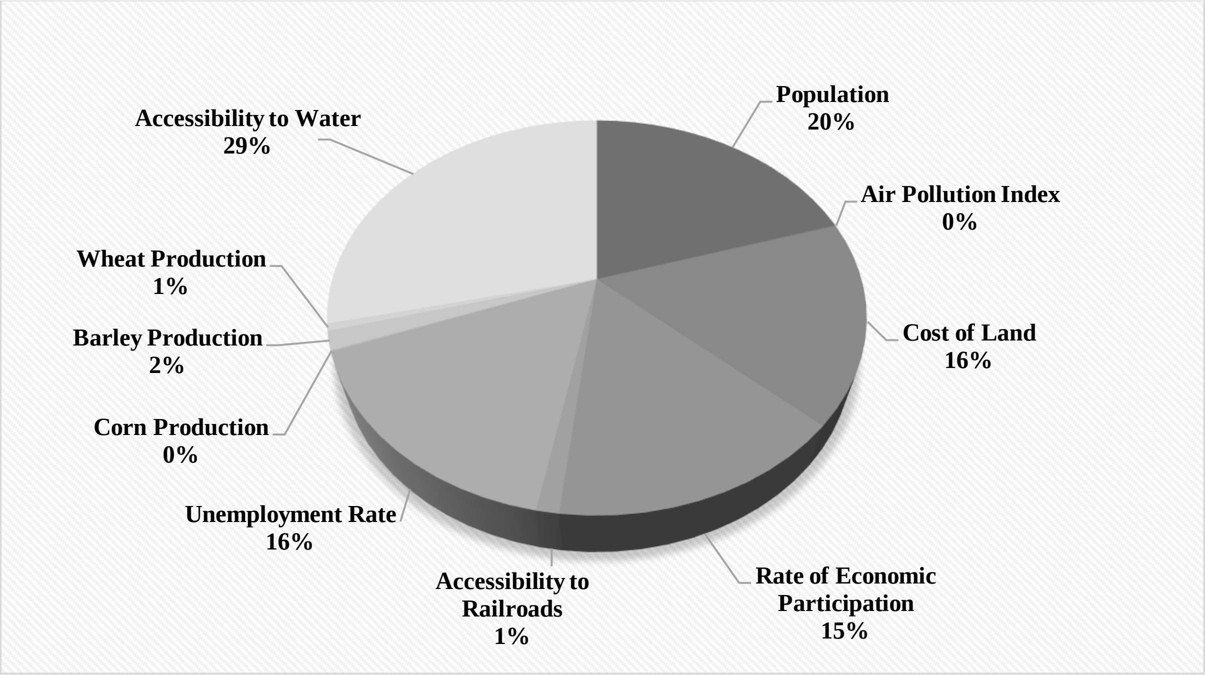


Fig 4. The weight of each factor in making performance efficiency by Z-number DEA model

4-5- Verification and validation

According to step 6, the obtained results of Z-number DEA model are validated by FDEA model. The obtained results indicate that optimum α-cut acquired for FDEA model is equal to 0.01. Figure 5 demonstrates the comparison between correlations of various α-cuts. The obtained results of FDEA for ranking DMUs are presented in table 9. The correlation coefficient between obtained ranks for DMUs using Z-number DEA and FDEA model is calculated equal to 0.873. Therefore, we can conclude that the results of Z-number DEA are verified and validated by FDEA model. Table 10 indicates the obtained results of Z-number DEA along with FDEA model. The comparison between obtained average efficiency scores of Z-number DEA and FDEA model indicates the superiority of Z-number DEA model versus FDEA model due to higher efficiency mean.

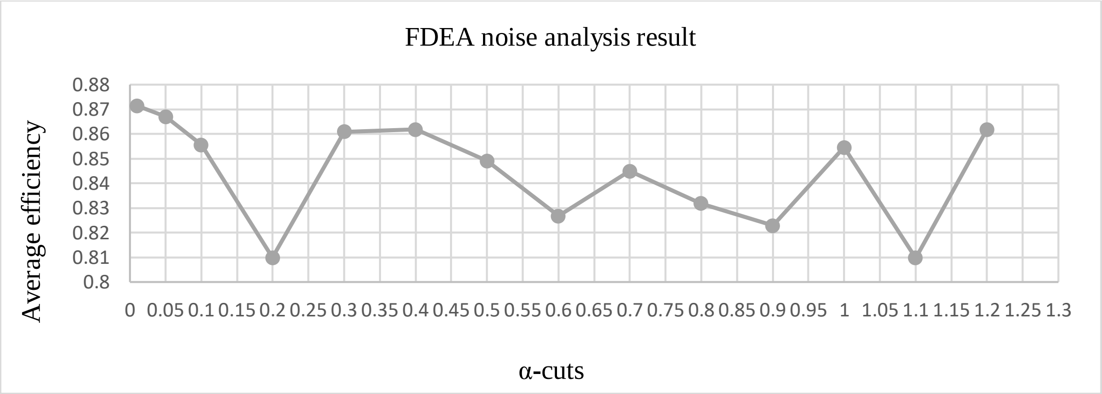


Fig 5. Comparison between average correlations of various α-cuts using noise analysis for FDEA model

Table 9. Results of full ranking FDEA model (α= 0.01*)*

DMU	Efficiency	Rank	DMU	Efficiency	Rank
Ardabil	1	2.024029	10	Razavi Khorasan	16
East Azerbaijan	2	1.105922	29	Nourth Khorasan	17
West Azerbaijan	3	1.109806	28	Khuzestan	18
Bushehr	4	1.906552	12	Kohgiluyeh and Boyer-ahmad	19
Chaharmahal and Bakhttiari	5	2.180735	7	Kurdistan	20
Isfahan	6	1.121717	27	Lorestan	21
Fars	7	1.170834	26	Markazi	22
Gilan	8	1.194721	25	Mazandaran	23
Golestan	9	1.954109	11	Qazvin	24
Hamedan	10	1.331452	24	Qom	25
Hormozgan	11	1.380971	22	Semnan	26
Ilam	12	4.19905	1	Sistan and Baluchestan	27
Kerman	13	1.706988	18	Tehran	28
Kermanshah	14	1.667824	19	Yazd	29
South Khorasan	15	2.823434	4	Zanjan	30

Table 10. Results comparison of Z-number DEA and FDEA model

Provinces	Z-number ranking (α=0.01)	FDEA ranking (α=0.01)
Ardabil	13	10
East Azerbaijan	26	29
West Azerbaijan	27	28
Bushehr	9	12
Chaharmahal and Bakhttiari	5	7
Isfahan	28	27
Fars	29	26
Gilan	25	25
Golestan	18	11
Hamedan	23	24
Hormozgan	22	22
Ilam	1	1
	11	18

Table 10. Continued

Provinces	Z-number ranking (α=0.01)	FDEA ranking (α=0.01)
	Kerman	19
South Khorasan	Kermanshah	4
Razavi Khorasan	24	23
Nourth Khorasan	6	8
Khuzestan	16	14
Kohgiluyeh and Boyer-ahmad	3	3
Kurdistan	20	21
Lorestan	7	5
Markazi	19	20
Mazandaran	17	15
Qazvin	14	17
Qom	11	13
Semnan	2	2
Sistan and Baluchestan	15	6
Tehran	30	30
Yazd	8	9
Zanjan	10	16

5- Conclusion and future research

Excessive use of fossil fuels has caused many environmental problems for many countries. Besides the environmental issues, many countries have oil-dependent economy. Therefore, finding new sources of renewable energy is very important. Many researchers have investigated new sources of renewable energy in past decades. One of the identified potential solutions to resolve the stated problem is biomass. Biomass mostly refers to organic matters which can produce energy. Various types of biomass are introduced in the past decades including wood and agricultural residues, food crops, and even municipal solid wastes. Burning agricultural residues to produce heat in various types of plants has attracted many researchers in the field of renewable energy. Researchers have shown that one of the strategic decisions in establishment of agricultural residues based plants, is location problem. Because mismatch between agricultural lands and biomass plants can lead to high transportation costs and related carbon dioxide emissions. Iran is one of the countries that suffers from air pollution due to high use of fossil fuels. Power generation in Iran is mostly based on fossil fuels and is one of the main sources of carbon dioxide emissions. Considering the thriving agricultural industry in Iran, establishment of agricultural residues based plants for power generation can be a reliable source of renewable energy. In order to determine the optimal location of the plant, we have presented an integrated approach based on Z-number DEA, FDEA, and statistical methods by considering the economic, social, and environmental aspects. Since agricultural industry is a seasonal industry, and agricultural crops production rates are changing during a year, many researchers have suggested using co-firing plants. The presented algorithm by considering the quantitative data regarding the considered criteria, and experts' judgment regarding the reliability of the gathered data can help decision makers to select optimal alternative for establishment of co-firing power plant based on agricultural residues and natural gas. This paper suggests following directions future research: (i) investigating the other parameters of the power plant such as capacity and size; (ii) evaluation of other biomass crop types.

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Appendix I

Table I. Raw data

DMU	Population (10000)	Air Pollution Index	Cost of Land (1000 Rials)	Rate of Economic Participation	Railroad (Km)	Unemployed Rate	Production Rate of Corn (Ton)	Production Rate of Barley (Ton)	Production Rate of Wheat (Ton)	Water Accessibility
	Mean	Mean	Mean	mean	Mean	Mean	mean	Mean	Mean	Mean
Ardabil	124.8488	17.8	12052	15.6	180	12.8	74,904	131,497	432,461	66,621
East Azerbaijan	308.0576	14.6	16832	9.3	102	10.9	39,858	76,120	457,676	155,548
West Azerbaijan	372.462	18.6	17823	10.1	365	7.3	3,543	127,869	417,188	216,828
Bushehr	103.2949	15.9	17274	12.8	45	9.7	2,120	10,124	109,448	76,908
Chaharmahal and Bakhttiari	89.5263	13.6	16115	14.1	86	16.4	NA	35,860	119,191	40,248
Isfahan	487.9312	27.1	24529	17	620	13.8	908	188,094	204,311	349,734
Fars	459.6658	9.6	22901	12.2	484	12.1	208,487	251,523	1,150,000	151,967
Gilan	248.0874	12.1	17092	17.5	15	11	186	7,280	8,121	114,013
Golestan	177.7014	12	12560	16.3	187	11.8	5,424	120,213	734,783	69,444
Hamedan	175.8268	13.7	20335	10.1	175	8.5	43,880	207,872	598,000	92,031
Hormozgan	157.8183	17.1	17534	18.9	613	11.9	37,069	1,781	47,497	92,612
Ilam	55.7599	15.6	9274	14.4	NA	11.6	64,813	48,400	246,598	32,732
Kerman	293.8988	14.1	11925	9.3	551	7.9	103,290	54,000	165,892	104,772
Kermanshah	194.5227	14.4	15221	13.1	NA	17.6	305,608	262,600	888,848	113,857
South Khorasan	66.2534	15.3	16000	15.5	317	8.6	NA	46,983	53,439	32,260
Razavi Khorasan	599.4402	14.8	20029	14.8	422	13.3	NA	289,550	523,658	131,831
Nourth Khorasan	86.7727	14.5	18000	16.5	NA	11.1	NA	77,503	191,190	32,818
Khuzestan	453.172	28.9	14992	11.1	673	10.9	491,963	143,281	1,260,956	315,508
Kohgiluyeh and Boyer-ahmad	65.8629	18.9	9997	9.6	155	17.7	13,000	33,300	168,179	31,831
Kurdistan	149.3645	13.5	16158	9.3	121	13.3	22,754	41,478	661,097	87,188
Lorestan	175.4243	12.5	10356	9.7	156	13.3	18,422	162,016	372,664	98,127.8
Markazi	141.3959	13.7	19951	10.7	288	7.9	262	151,897	366,044	102,843
Mazandaran	307.3943	12.9	14276	18.5	479	12.1	400	45,804	158,341	216,466

Table I. Continued

DMU	Population (10000)	Air Pollution Index	Cost of Land (1000 Rials)	Rate of Economic Participation	Railroad (Km)	Unemployed Rate	Production Rate of Corn (Ton)	Production Rate of Barley (Ton)	Production Rate of Wheat (Ton)	Water Accessibility
	Mean	Mean	Mean	mean	Mean	Mean	mean	Mean	Mean	Mean
Qazvin	120.1565	15.8	19363	13.6	122	11.7	48,629	106,334	283,057	74,856
Qom	115.1672	18.8	18665	7.5	352	11.3	NA	69,046	31,209	90,457
Semnan	63.1218	13.9	11268	16.4	879	8.4	NA	46,888	91,397	53,381
Sistan and Baluchestan	253.4327	15.3	10990	11.2	529.112	11.5	25,845	27,304	178,901	95,800
Tehran	1218.3391	26.7	41320	10.9	790	8.1	NA	99,675	117,282	1,373,082
Yazd	107.4428	12.5	12789	12.6	704	11.2	20,054	9,857	44,110	89,334
Zanjan	101.5734	17.7	15345	11.6	195	9.6	NA	36,037	36,100	61,412

Appendix II

Table II: Fuzzy data

DMU	Population (10000)			Air Pollution Index			Cost of Land (1000 Rials)			Rate of Economic Participation			Railroad (Km)		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
Ardabil	96.9688	124.8488	152.7280	12.7	17.8	182	7415	12052	16689	11.85	15.6	19.35	180	180	180
East Azerbaijan	280.1776	308.0576	335.9375	11.5	14.6	281	12195	16832	21469	5.55	9.3	13.05	102	102	102
West Azerbaijan	344.582	372.462	400.3419	11.7	18.6	231	13186	17823	22460	6.35	10.1	13.85	365	365	365
Bushehr	75.41495	103.2949	131.1748	13.7	15.9	242	12637	17274	21911	9.05	12.8	16.55	45	45	45
Chaharmahal and Bakhttiari	61.6463	89.5263	117.4062	10.7	13.6	175	11478	16115	20752	10.35	14.1	17.85	86	86	86
Isfahan	460.0512	487.9312	515.8111	14.8	27.1	195	19892	24529	29166	13.25	17	20.75	620	620	620
Fars	431.7858	459.6658	487.5457	8.6	9.6	161	18264	22901	27538	8.45	12.2	15.95	484	484	484
Gilan	220.2074	248.0874	275.9673	9.6	12.1	198	12455	17092	21729	13.75	17.5	21.25	15	15	15
Golestan	149.8214	177.7014	205.5813	8.7	12	186	7923	12560	17197	12.55	16.3	20.05	187	187	187
Hamedan	147.9468	175.8268	203.7067	12.5	13.7	143	15698	20335	24972	6.35	10.1	13.85	175	175	175
Hormozgan	129.9383	157.8183	185.6982	11.2	17.1	193	12897	17534	22171	15.15	18.9	22.65	613	613	613
Ilam	27.8799	55.7599	83.6398	12.8	15.6	229	4637	9274	13911	10.65	14.4	18.15	0	0	0
Kerman	266.0188	293.8988	321.7787	11.2	14.1	186	7288	11925	16562	5.55	9.3	13.05	551	551	551
Kermanshah	166.6427	194.5227	222.4026	11.9	14.4	218	10584	15221	19858	9.35	13.1	16.85	0	0	0
South Khorasan	38.3734	66.2534	94.1333	10.3	15.3	126	11363	16000	20637	11.75	15.5	19.25	317	317	317
Razavi Khorasan	571.5602	599.4402	627.3201	11.1	14.8	136	15392	20029	24666	11.05	14.8	18.55	422	422	422
Nourth Khorasan	58.8927	86.7727	114.6526	11.8	14.5	118	13363	18000	22637	12.75	16.5	20.25	0	0	0
Khuzestan	425.292	453.172	481.0519	15.5	28.9	374	10355	14992	19629	7.35	11.1	14.85	673	673	673
Kohgiluyeh and Boyer-ahmad	37.9829	65.8629	93.7428	13.8	18.9	261	5360	9997	14634	5.85	9.6	13.35	155	155	155
Kurdistan	121.4845	149.3645	177.2444	11.5	13.5	176	11521	16158	20795	5.55	9.3	13.05	121	121	121
Lorestan	147.5443	175.4243	203.3042	10.1	12.5	142	5719	10356	14993	5.95	9.7	13.45	156	156	156
Markazi	113.5159	141.3959	169.2758	12.8	13.7	179	15314	19951	24588	6.95	10.7	14.45	288	288	288
Mazandaran	279.5143	307.3943	335.2742	9.5	12.9	161	9639	14276	18913	14.75	18.5	22.25	479	479	479
Qazvin	92.2765	120.1565	148.0364	13.7	15.8	229	14726	19363	24000	9.85	13.6	17.35	122	122	122
Qom	87.2872	115.1672	143.0471	14.1	18.8	252	14028	18665	23302	3.75	7.5	11.25	352	352	352

Table II: Continued

DMU	Population (10000)			Air Pollution Index			Cost of Land (1000 Rials)			Rate of Economic Participation			Railroad (Km)		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
Semnan	35.2418	63.1218	91.0017	11.2	13.9	201	6631	11268	15905	12.65	16.4	20.15	879	879	879
Sistan and Baluchestan	225.5527	253.4327	281.3126	11.8	15.3	179	6353	10990	15627	7.45	11.2	14.95	529.112	529.112	529.112
Tehran	1190.459	1218.339	1246.2190	13	26.7	274	36683	41320	45957	7.15	10.9	14.65	790	790	790
Yazd	79.5628	107.4428	135.3227	10.9	12.5	159	8152	12789	17426	8.85	12.6	16.35	704	704	704
Zanjan	73.6934	101.5734	129.4533	13.1	17.7	269	10708	15345	19982	7.85	11.6	15.35	195	195	195

Table III: Fuzzy data (Continued)

DMU	Unemployed Rate			Production Rate of Corn (Ton)			Production Rate of Barley (Ton)			Production Rate of Wheat (Ton)			Water Accessibility		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
Ardabil	9.15	12.8	16.45	74811	74,904	74,997	130606.5	131,497	132387.5	428,401	432,461	436,522	50,706	66,621	82,537
East Azerbaijan	7.25	10.9	14.55	39765	39,858	39,951	75229.5	76,120	77010.5	453,616	457,676	461,737	139,633	155,548	171,464
West Azerbaijan	3.65	7.3	10.95	3450	3,543	3,636	126978.5	127,869	128759.5	413,128	417,188	421,249	200,913	216,828	232,744
Bushehr	6.05	9.7	13.35	2027	2,120	2,213	9233.5	10,124	11014.5	105,388	109,448	113,509	60,993	76,908	92,824
Chaharmahal and Bakhttiari	12.75	16.4	20.05	0	0	0	34969.5	35,860	36750.5	115,131	119,191	123,252	24,333	40,248	56,164
Isfahan	10.15	13.8	17.45	814.5	908	1,001	187203.5	188,094	188984.5	200,251	204,311	208,372	333,819	349,734	365,650
Fars	8.45	12.1	15.75	208394	208,487	208,580	250632.5	251,523	252413.5	1,145,940	1,150,000	1,154,061	136,052	151,967	167,883
Gilan	7.35	11	14.65	93	186	279	6389.5	7,280	8170.5	4,061	8,121	12,182	98,098	114,013	129,929
Golestan	8.15	11.8	15.45	5331	5,424	5,517	119322.5	120,213	121103.5	730,723	734,783	738,844	53,529	69,444	85,360
Hamedan	4.85	8.5	12.15	43787	43,880	43,973	206981.5	207,872	208762.5	593,940	598,000	602,061	76,116	92,031	107,947
Hormozgan	8.25	11.9	15.55	36976	37,069	37,162	890.5	1,781	2671.5	43,437	47,497	51,558	76,697	92,612	108,528
Ilam	7.95	11.6	15.25	64720	64,813	64,906	47509.5	48,400	49290.5	242,538	246,598	250,659	16,817	32,732	48,648
Kerman	4.25	7.9	11.55	103197	103,290	103,383	53109.5	54,000	54890.5	161,832	165,892	169,953	88,857	104,772.101	120,688
Kermanshah	13.95	17.6	21.25	305515	305,608	305,701	261709.5	262,600	263490.5	884,788	888,848	892,909	97,942	113,857	129,773
South Khorasan	4.95	8.6	12.25	0	0	0	46092.5	46,983	47873.5	49,379	53,439	57,500	16,345	32,260	48,176
Razavi Khorasan	9.65	13.3	16.95	0	0	0	288659.5	289,550	290440.5	519,598	523,658	527,719	115,916	131,831	147,747
Nourth Khorasan	7.45	11.1	14.75	0	0	0	76612.5	77,503	78393.5	187,130	191,190	195,251	16,903	32,818	48,734
Khuzestan	7.25	10.9	14.55	491870	491,963	492,056	142390.5	143,281	144171.5	1,256,896	1,260,956	1,265,017	299,593	315,508	331,424
Kohgiluyeh and Boyer-ahmad	14.05	17.7	21.35	12907	13,000	13,093	32409.5	33,300	34190.5	164,119	168,179	172,240	15,916	31,831	47,747
Kurdistan	9.65	13.3	16.95	22661	22,754	22,847	40587.5	41,478	42368.5	657,037	661,097	665,158	71,273	87,188	103,104
Lorestan	9.65	13.3	16.95	18329	18,422	18,515	161125.5	162,016	162906.5	368,604	372,664	376,725	82,212	98,127.8	114,043
Markazi	4.25	7.9	11.55	169	262	355	151006.5	151,897	152787.5	361,984	366,044	370,105	86,928	102,843	118,759
Mazandaran	8.45	12.1	15.75	307	400	493	44913.5	45,804	46694.5	154,281	158,341	162,402	200,551	216,466	232,382
Qazvin	8.05	11.7	15.35	48536	48,629	48,722	105443.5	106,334	107224.5	278,997	283,057	287,118	58,941	74,856	90,772
Qom	7.65	11.3	14.95	0	0	0	68155.5	69,046	69936.5	27,149	31,209	35,270	74,542	90,457	106,373

Table III. Continued

DMU	Unemployed Rate			Production Rate of Corn (Ton)			Production Rate of Barley (Ton)			Production Rate of Wheat (Ton)			Water Accessibility		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
Semnan	4.75	8.4	12.05	0	0	0	45997.5	46,888	47778.5	87,337	91,397	95,458	37,466	53,381	69,297
Sistan and Baluchestan	7.85	11.5	15.15	25752	25,845	25,938	26413.5	27,304	28194.5	174,841	178,901	182,962	79,885	95,800	111,716
Tehran	4.45	8.1	11.75	0	0	0	98784.5	99,675	100565.5	113,222	117,282	121,343	1,357,167	1,373,082	1,388,998
Yazd	7.55	11.2	14.85	19961	20,054	20,147	8966.5	9,857	10747.5	40,050	44,110	48,171	73,419	89,334	105,250
Zanjan	5.95	9.6	13.25	0	0	0	35146.5	36,037	36927.5	32,040	36,100	40,161	45,497	61,412	77,328