Location planning of bioethanol plants from agricultural crop residues for fuel cells using DEA

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Abstract

Bioethanol has recently been considered as a good substitute for fossil fuels. It is considered as a kind of biofuel that can be produced from agricultural crop residues like corn, wheat, potato, sugarcane and many others. Ethanol is most often used as an engine fuel, mainly as a biofuel additive for gasoline. The purpose of this study is to investigate availability of agricultural crop residues, then identify the most suitable locations for bioethanol production in the Fars Province of Iran. Complete reviews of available crop residues for twenty six cities of the province are investigated for this purpose. A Multi Criteria Decision Making (MCDM) approach of Data Envelopment Analysis (DEA) is performed to rank cities in order to find the most suitable location to install ethanol manufacturing plant. Six major criterions are investigated to perform DEA methodology which includes two outputs of population and amount of available ethanol, and four outputs including distance, air pollution, price of ethanol, and price of land. Then Anderson-Peterson model of DEA for ranking was performed. Results indicate that Shiraz, Marvdasht, Eghlid, and Sepidan cities rank first to fourth respectively.

Keywords

Bioethanol; Data Envelopment Analysis (DEA); Location planning; Production. . Agricultural waste;

1. Introduction

Advances in manufacturing technology have led to rapidly growing numbers of cars and machineries that use fossil fuels. Gasoline has many detrimental effects on the environment; in addition, fossil fuel reserves are rapidly decreasing and will eventually be diminished by growing population worldwide. There are many solutions to resolve this problem like. One of these solutions is to replace fossil fuels with appropriate alternative fuels. Ethanol is one of these alternatives that have much lower environmental impacts and also can be easily used in combination with petrol or completely replace it (Mirfattah & Saleh, 2007).

In the not too distant future, humans will be faced with two major crises; one is the environmental pollution caused by fossil fuel combustion and other is the rapidly diminishing fuel sources. In 1979, Iranians were using nearly 20 barrels of oil equivalent energy to produce one million Rials domestic product; this value reached to 36 barrels in 1988 and 41 barrels of oil equivalent energy in 1995 which shows a 100% increase compared to 1979. Despite rationing the subsidized petrol and increase in refining capacity, Iran still imports a large portion of its domestic demand for petrol. So given the current situation and growth of energy consumption and limited fossil fuel reserves developing the alternative sources of energy seems completely necessary (Najafi, 2011; Ghadirianfar et al, 2013; Moeenipanah, 2012).

In the past, tetraethyl lead (TEL) or tetra methyl lead (TML) was being used to improve the octane number of petrol, but they are now obsolete or rarely used, thanks to their environmental impacts and toxicity of lead oxides. Today, lead compounds of petrol are replaced by oxygen-generating compounds and petrol can also be replaced by oxygenated substances such as alcohols and ethers which can lead to higher octane number and consequently to improved combustion and reduced emission of harmful substances such as carbon monoxide, volatile organic compounds, saturated hydrocarbons and so on (Ja'fari-Nejad, 2013).

In this study, we will assess various cities located in Fars province in Iran, in terms of available resources for the production of ethanol. To reach our objective, we will analyze the parameters as one does in a location problem and then rank and prioritize these cities in terms of suitability to produce ethanol. The problem discussed in this study then is to find the best location in Fars province to build an ethanol plant. It should be noted that raw material for ethanol production is considered as agricultural residue created within Fars province.

Significant water resources and high variety of agricultural products has made Fars province one of the leading provinces of Iran in this regard. Fars province is a major producer of wheat, barley, maize, sugar beet and potato. Agricultural residue created by this industry remains largely unused or is burned off or at best, is used as livestock feed; using these agricultural residues to produce ethanol, will significantly reduce the ethanol production cost and will also reduce the environmental impacts caused by burning these residues.

For twenty-one consecutive years, Fars province has ranked first among Iran's provinces in terms of wheat production (amar.org.ir). It also holds top ranks in the production of other agricultural products. Thus, using the residue produced in this province for the production of ethanol can be a stepping stone to reduce the reliance on fossil fuels.

Location planning with DEA approach has been studied and investigated by many researchers. Babazadeh et al. (2015) have studied location optimization for biofuel production using non-radial DEA. Nikolaus Ederer (2015) investigated a DEA approach for evaluating operating cost efficiency of wind farms. Jingzheng Ren et al. (2014) have determined the life cycle energy efficiency of six biofuel systems in China with Data Envelopment Analysis. Houshyar et al. (2015) used a hybrid multi fuzzy and DEA modeling to evaluate the sustainability and efficiency of corn production with regard to energy consumptions in the Fars province, Iran. Jing-Li et al. (2014) have evaluated the efficiency of CO_2 utilization technologies in China with DEA approach. Azadeh et al. (2014) have studied wind power generation-transmission systems location optimization used hierarchical fuzzy DEA. Ghadirian-far et al. (2013) have studied ethanol production and consumption in Iran. They found that Iran had enough potential for ethanol production from agricultural waste. Fallahzadeh (2009) ranked the provinces of Iran for producing ethanol which results of his study show that Fars province is one of the better provinces in Iran. Hyung Kim et al. (2011) have studied the feasibility of ethanol production from food waste and concluded the study with results that show the feasibility of ethanol production from food waste. Sadeghi (2012) at a research ranked the cities of East Azarbayjan province of Iran for wind power station using DEA approach. Ghafurian-Yavar-Panah et al. (2014) determined the efficiency of bank system and evaluated the best input and output criterions for bank system. Gupta & Verma (2015) have reviewed current technologies for sustainable bioethanol production from agro-residues. They found that maize, sugarcane and sugar beets are major traditional agricultural crops used as bio-ethanol production. They also concluded that "agro-residues biomass has been proposed to be one of the main renewable resources for cost-effectively attractive bio- ethanol production".

To find the best location to build an ethanol plant, we will assess 26 cities of this province with respect to input and output criteria affecting this subject. Factors affecting the efficiency of ethanol production plants include available raw materials, ethanol production cost (per m^3), city's air pollution, city's population, distance from the provincial capital (for distribution and sales purposes), and the price of agricultural land (to increase the production).

In order to select the best locations, the cities of the province will be prioritized. Data envelopment analysis (DEA) techniques will be used for this purpose. The reason behind using this technique is the largely heterogeneous nature of criteria and factors affecting the efficiency of decision making units (DMUs); for example, data regarding air pollution, raw material, and population are very different in nature. Data envelopment analysis is a method for evaluating the relative efficiency of some DMUs with respect to a number of inputs and outputs and therefore is a suitable method for comparing the candidate sites for the construction of ethanol production plant.

There have been many studies related to renewable energy areas in Iran including wind and energy which could help to reduce carbon dioxide in Iran. Authors have performed numerous research works related to renewable energy areas (Shamshirband et al., 2015; Mostafaeipour & Abesi, 2010; Mohammadi et al., 2016; Shamshirband et al., 2016; Mostafaeipour et al., 2014; Eratum to: Shamshirband et al., 2016; Mostafaeipour & Sadeghian, 2005; Sajjadi et al., 2016; Hosseini-Ezabadi et al., 2015; Mohammadi et al., 2014; Mostafaeipour, 2011; Mostafaeipour et al., 2016). Implementing renewable energies like ethanol could be a major step to combat climate change in Iran.

The rest of this paper is structured as follows: geographic characteristics of Fars Province is presented in Section 2. Section 3 describes ethanol thoroughly. In Sections 4, six criteria affecting the efficiency of ethanol production plant are introduced. In Section 5, Agricultural crop residue for ethanol production in the province are presented. In Section 6, methodology is presented while analysis is done in section 7 to prioritize cities of Fars Province for ethanol production plant. Finally, conclusion is drawn in Section 8.

2. Geographic characteristics

Fars province is one of the thirty-first provinces of Iran with available agricultural lands which are suitable for harvesting different crops.

It is located in south of the country, and its administrative center is city of Shiraz . It has an area of 122607.943 km². In 2011, this province had a population of 4.59 millions, of which 67.6% were registered as urban dwellers (urban/suburbs), 32.1% villagers (small town/rural), and 0.3%

nomad tribes (www.amar.org.ir). For this research work, 26 cities distributed in different parts of the Fars province are investigated.

3. Ethanol

Ethanol or ethyl alcohol with the chemical formula C_2H_5OH is a colorless liquid with a pungent odor that is easily burns, producing water and carbon dioxide; Ethanol evaporates quickly and does not have any significant environmental impact (Ja'fari-Nejad, 2013).
Ethanol was first used as a supplement for petrol in 1930, but MTBE has also been widely used for this purpose since 1973. In Iran, MTBE with the chemical formula $C_5H_{12}O$ (which is a special type of ether) has been used in petrol production since 2002 (Ja'fari-Nejad, 2013).
The use of ethanol as a fuel or combined with petrol was introduced in 1970, But constant fluctuations in oil prices has caused major ups and downs in the use of ethanol and investments in ethanol production. But todays' concerns are beyond prices and are more focused on the dangers and consequences of environmental pollution, greenhouse gases, climate change and global warming (Ja'fari-Nejad, 2013).
Ethanol is produced from raw agricultural products, including sugar cane, sugar beet, cereals, potatoes and other such products (containing sugar or starch). Substances containing sugar are directly converted into ethanol; but substances containing starch or cellulose must first undergo hydrolysis to be converted into sugar and then undergo fermentation process to become ethanol (Najafi, 2011; Ja'fari-Nejad, 2013).
Cereals, especially maize and wheat, are currently the major sources of ethanol production, which despite advances in technology impose a high production cost. But the use of agricultural residue to produce ethanol can significantly reduce the production costs and can lead to a trend by which using and producing ethanol become cost-effective (Naebzadeh, 2016)
Since 1980s, the world's major consumers of ethanol have been the automobiles which use 70 to 80 percent (over 80% by another account) of global production as fuel or fuel additives (Najafi, 2011; Ja'fari-Nejad, 2013).

3.1. Ethanol production processes

The process of producing ethanol from different types of agricultural products like wheat, barley, maize, sugar beet, and potatoes is available. Sugar fermentation process is the method used in 98% of cases. Based on the type of raw materials, method of work is different (Najafi, 2011).

3.2. Global production

Currently, Brazil and the United States account for about 50 percent of global biofuels production. China is in the third place and about a third of the country's maize production enters into the petrol tanks. In Brazil, ethanol is mainly produced from sugar cane but Americans mainly use maize for this purpose (Najafi, 2011; Naebzadeh, 2016).
The ethanol production by different countries in 2003 and 2004 is shown in Table 1 (Ja'fari-Nejad, 2013). The difference between production capacity of Brazil, United States and China and that of other countries is clearly visible.

Table 1: The ethanol production for different countries.

Country	2003	2004
Brazil	14428	15338
America	10900	13950
China	3400	3650
India	190	2000
France	817	830
Russia	745	760
Spain	304	420
South Africa	404	409
Britain	410	400
Arabia	350	340
Ukraine	284	290
Thailand	250	280
Germany	280	270
Canada	240	245
Italy	204	210

3.3. Environmental impacts

Ethanol contains 35% oxygen and adding it to petrol results in more complete combustion of fuel and reducing emissions of pollutants from the exhaust. According to estimates of Canadian government, if 35% of the country's petrol contain 10% ethanol, greenhouse gas emissions will decrease by 1.8 million tons per year which is equivalent to removing 400000 vehicles from the roads of this country (Ja'fari-Nejad, 2013).

In addition, ethanol is a renewable fuel which makes it more preferable to MTBE. MTBE is highly resistance to biodegradation, so it can spread to places far distant from the source of pollution, leading to negative effects on the quality of underground water (Ja'fari-Nejad, 2013).

4. Six criteria affecting the efficiency of ethanol production plant

In this study, six criteria that can affect the efficiency of ethanol production plant are considered. Input criteria are those that an increase in them decreases the efficiency; in this study, input criteria include distance from the provincial capital, air pollution, land price, and manufacturing cost (due to raw materials) per liter of ethanol, in each city. Output criteria are those that an increase in them increases the efficiency; in this study, output criteria include population and possible ethanol production capacity. The data used in this study are related to the years 2007 to 2012.

4.1. Criteria

Given the variety of factors affecting the efficiency of ethanol production, the method of collecting data related to each of these criteria is different. In the following, a description about each of these criteria will be presented. Data related to each of the six criteria considered in this paper, have been collected from different sources and some of them have been obtained by assessing the relationship between desired parameters and available data. The remainder of this section discusses the detail regarding these criteria and their data.

4.1.1. Distance between each city and provincial capital (Shiraz)

Distance between each city and provincial capital (Shiraz) was collected which are considered as input criteria (www.lemo.ir). According to these data, city of Mohr is the one farthest from provincial capital Shiraz.

4.1.2. Air Pollution

No records regarding the pollution of cities in Fars province is currently available, so in this study, pollution of cities was estimated based on national CO_2 emission per capita and the population of each city (Ghasemifar, 2013).
Air pollution was estimated with respect to Iran's per capita CO_2 emission and population of each city and by multiplying these two factors by each other (www.amar.org.ir ; Ghasemifar, 2013; Jos et al., 2013). Cities population was gathered from latest available statistics reports and national CO_2 emission per capita was considered 5.5 tons per capita. By this assumption, a city that has a larger population also has a higher degree of air pollution; by this measure, Shiraz is the most polluted city in the Fars province and Pasargad has the cleanest air quality in this province.

4.1.3. Land cost

According to internet searches and queries from the employees of local agriculture offices, price of agricultural land in each city of Fars province and even in regions around each city varies in a wide range and is mainly based on the availability of water resources. The average price of land was estimated and considered for each city so that it can be reasonably used in problem solving process. In general, the price of land in each city has a direct relationship with the population, water resources and proximity to the provincial capital. By this estimation, Shiraz and Jahrom have the highest land prices and land prices are lower in smaller cities (www.fars.agri-jahad.ir).

4.1.4. Price of ethanol

Different cities produce different amounts of each agricultural product, so the residue content of each agricultural product needed to produce one cubic meter of ethanol was estimated, and then the price of each cubic meter of ethanol was calculated with respect to the price of used residue.

4.1.5. Population

Cities' population was obtained from the statistics site reporting the results of 2011 population and housing census (www.amar.org.ir). According to this data, Shiraz is the most populous city and Sarvestan is the least populous city in the Fars province.

4.1.6. Amount of available ethanol

Each city's ethanol production capacity was estimated based on the amount of each agricultural product produced by each city during 5 consecutive years and also the percentage of residue produced by each of these products obtained from an article published in this regard. Percentages of residue for each product, ethanol produced by this residue (Najafim 2011; www.fars.agri-jahad.ir). Among all cities of Fars province, Marvdasht has the highest possible ethanol production capacity equal to 63448.6 cubic meters.

5. Agricultural crop residue for ethanol production in the province

Crops required for the production of ethanol include wheat, barley, maize, potato, sugar beet and even palm. Each of these products needs to undergo a different process tailored to its characteristics to

eventually be converted into ethanol. Since the process of converting palm to ethanol is very different from other products, in this study, we only consider 5 products of wheat, barley, maize, potato, and sugar beet and obtain other related data accordingly. Estimated amounts of ethanol production calculated based on the average values of 5-year data regarding the crops produced in each city are presented in the table below. The effect of residue percentage for each product is also applied to these data and results are presented in the same table. Amount of ethanol producible by each of these products is also calculated and results were used in DEA calculation.
Amount of ethanol producible by each of these products is different, so the possible amount of ethanol production in each city is calculated by considering the percentage of ethanol producible by each product, and are presented in the following (Najafi, 2011; www.fars.agri-jahad.ir).

6. Methodology

The CCR model, which is type of data envelopment analysis (DEA) approach, is used to rank and prioritize the cities of Fars province. More details information is provided in the following sections.
Farrell has defined the efficiency of an enterprise as the production of output as much as is possible with a given input. This means that we should either maximize the output produced by a fixed level of input (output oriented efficiency evaluation) or minimize the input used for producing a fixed level of output (input oriented efficiency evaluation) (Alem Tabriz & Imanipour, 2009).
There are two approaches to assess the efficiency: parametric and nonparametric, both including deterministic and stochastic methods. Parametric methods are regression-based approaches where a special form will be assumed for the production function, while nonparametric methods do not operate under this assumption and use mathematical programming techniques to calculate the relative efficiency (Pourkazemi, 2003; Nasiri et al, 2013).
DEA is a non-parametric mathematical programming model with multiple inputs and outputs that assesses the efficiency of the decision making units. This model was first presented by Edward Rhodes (under advisement of Cooper) in 1976 at the University of Carnegie as a doctoral dissertation assessing the students' achievements in American public Schools. This technique was previously introduced by Farrell in 1957 to estimate the efficiency of American agricultural sector, although with one input and one output; but Charnes, Cooper & Rhodes developed Farrell's approach, and Edward Rhodes was the first one who used this technique with multiple inputs and outputs. Since this model was presented by Charnes, Cooper and Rhodes, it was named as CCR model (which is composed of the first letters of their names), and was presented in a paper published in 1978 titled measuring the efficiency of decision making units (Azizi, 2012; Olfat, 2010; Farsijani, 2011).
The DEA is based on a series of optimizations procedures performed by linear programming technique. After these optimizations, linear programming technique determines that whether the target DMU is located on the efficient frontier or outside, thus detecting efficient and inefficient units. DEA technique envelopes all data and therefore is called data envelopment analysis.
DEA model is in mathematical form; this form of model was coded and run in GAMS software.
The mathematical model of DEA is presented as followings (Toloue & Joshaghani, 2013):

$$Max\ Z = \sum_{r=1}^{s} u_r y_{ro} \qquad (1)$$

$Subject\ to$:

$$\sum_{i=1}^{m} v_i x_{io} = 1 \qquad (2)$$

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0 \quad , \quad j = 1, \dots, n \qquad (3)$$

$$v_i \geq 0 \quad , \quad i = 1, \dots, m \qquad (4)$$

$$u_r \geq 0 \quad , \quad r = 1, \dots, s \qquad (5)$$

7. Analysis

In this paper, we used input-oriented CRR model to assess the efficiency of all factors. This model was implemented for each DMU (each city of the Fars province), and the relative efficiency of each DMU was obtained (Toloue & Joshaghani, 2013).

The program output shows that all units have a relative efficiency of 1. This means that all DMUs are efficient and are located on DEA-efficient frontier. In other words this analysis shows that all 26 units (DMU), which all have a relative efficiency equal to 1, are efficient and there is no inefficient unit among these DMUs. This result does not give us any meaningful information about the rank and prioritization of the cities and in regard with optimum location for the construction of ethanol plant.

Since DEA gave DMUs identical efficiency scores, a different method must be used to prioritize these units. In similar studies, after implementing data envelopment analysis (DEA) model and identifying efficient units, Anderson-Peterson model has often been used to prioritize these units (Jadidi, 2012]. Andersen Petersen model provides an approach for ranking efficient units by allowing efficiency score of efficient unit P to be greater than 1. In other words, it removes P-th constraint in the DEA model to allow the unit p to be given an efficiency score greater than 1. Andersen Petersen mathematical model is as below (Mohammadzadeh, 2010).

Andersen Petersen model was coded and ran in the GAMS software for each DMU. These codes were written separately for 26 DMUs.

After applying Anderson- Peterson model for each DMU, their efficiency scores were obtained as is shown in Table 2. According to these results, the most efficient units are by order units 4, 23, 15 and 13, and other units have equal efficiency. So the result of ranking shows that the most suitable cities in Fars province to build an ethanol production plant are Shiraz, Marvdasht, Eghlid, and Sepidan respectively.

Table 2: Relative efficiency from Andersen Petersen.

Unit	**City**	**Relative efficiency**	**Unit**	**City**	**Relative efficiency**
DMU1	Abadeh	1	DMU14	Sarvestan	1
DMU2	Arsanjan	1	DMU15	Shiraz	21.57
DMU3	Estahban	1	DMU16	Farrashband	1
DMU4	Eghlid	1.491	DMU17	Fasa	1
DMU5	Bavanat	1	DMU18	Firuzabad	1
DMU6	Pasargad	1	DMU19	Ghirokarzin	1
DMU7	Jahrom	1	DMU20	Kazerun	1
DMU8	Khorrambid	1	DMU21	Larestan	1
DMU9	Khonj	1	DMU22	Lamerd	1
DMU10	Darab	1	DMU23	Marvdasht	3.226

DMU11	Rostam	1	DMU24	Mamasani	1
DMU12	Zarrindasht	1	DMU25	Mohr	1
DMU13	Sepidan	1.053	DMU26	Neiriz	1

8. Conclusions

Ethanol can be used as a supplement or substitute for gasoline, and since oil reserves are decreasing rapidly and in the near future even Iran which has huge reserves of oil and gas, will be faced with major problem in this regard, it seems that investment in ethanol industry and using ethanol as fuel in some applications is absolutely necessary. Renewable energy sources have lower adverse effects on the environment and on the other hand, using agricultural residue for ethanol production can lead to the reduction of pollution caused by eliminating these residues through traditional methods by a cost-effective approach.

Therefore, we suggest investors, especially public and state companies, to explore numerous investment options in ethanol production by agricultural residues in order to control and lead energy policy in regard with this sector and to achieve sustainable development and profit for themselves and region.

In this study, DMUs (cities) efficiency scores were calculated by considering several input and output criteria for DEA model, and implementing and solving the model in the GAMS software. But since all units had identical efficiency scores equal to one, identification of truly efficient DMUs at that stage was not possible.

Solution of DEA model provided a list of locations that have a good potential for ethanol production. So using other methods to eliminate inefficient DMUs and identify the efficient DMUs was necessary. Using Andersen Petersen model however only identified 4 units as the ones with higher efficiency scores and gave other cities the identical scores.

The most suitable location to build ethanol production plant was identified as Shiraz, and Marvdasht was second in the ranking. Therefore, we achieved our objective in this study which was the determination of most suitable location for the construction of ethanol production plant.

We suggest researchers who want to conduct further studies in this field to also review and examine the major researches and project carried out in Brazil and US in order to reach a better judgment and make better decisions regarding the course of their work.

We suggest researchers who want to work on subjects similar to this study, to also utilize other methods in addition to ones used in this paper in order to achieve a successful ranking and prioritization for all decision making units or cities.

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