Published as: Houshyar, E., Azadi, H., Almassi, M., Davoodi M.J.S. & Witlox, F. (2012) "Sustainable and efficient energy consumption of corn production in Southwest Iran: Combination of multi-fuzzy and DEA modeling." *Energy*, Vol. 44 (1), pp. 672-681.

Sustainable and Efficient Energy Consumption of Corn Production in Southwest Iran: Combination of Multi-Fuzzy and DEA Modeling

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Abstract: The goal of this study was to evaluate the sustainability and efficiency of corn production with regard to energy consumption in the Fars province, Southwest Iran. To reach the goal, fuzzy modeling and Data Envelopment Analysis (DEA) were employed. The fuzzy model included three sub-models which assessed the sustainability use of energy inputs, i.e. machinery, fuel, fertilizer, chemical, human power, seed, and electricity. Some DEA models like CCR (Charnes, Cooper and Rhodes), BCC (Banker, Charnes and Cooper) and SBM (Slack Based Measure) were applied in assessment of efficiency scores. Using non-hierarchical cluster analysis, 89 farmers were chosen in two clusters including 47 and 42 farmers as the first and second cluster, respectively. The farmers in cluster 2 used 44238.235 MJ/ha energy input which was 2500 MJ/ha more than the first cluster. The fuzzy modeling revealed that the sustainability indices were higher in the first cluster. However, the indices were in the ranges of very low to medium for all the farmers, representing that the current corn production system is not sustainable. Also, the DEA models revealed that the first cluster also held more efficient farmers. Since DEA defines a reference set of efficient for inefficient farmers to follow, lead inefficient farmers to improve their sustainability up to efficient ones. Therefore, efficient and inefficient farmers must change the trends of energy utilization for approaching even more sustainable production.
Keywords: fuzzy logic, DEA, energy input, corn.

1. Introduction

1.1. Energy and sustainability

Agriculture could be meant as the conversion of human, fossil and solar energies into food and fiber products [1;2]. The foundation of all agricultural production is the unique capability of plants to convert solar energy into stored chemical energy [3]. However, Plants are not particularly efficient at collecting solar energy. For instance, one hectare of green plants collect on average less than 0.1 percent of the solar energy reaching them [4], or during the 120-day growth season, roughly only ~ 0.7% of the solar energy is converted by corn plants into biomass

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[5]. One of the main factors that influence the sustainable crop cultivation is the amount of energy input in any form to produce a unit of a desirable crop [6]. In fact, sufficient food production that can ensure food security highly relies on the existence of enough energy. Human beings rely on various sources of energy range from human, animal, wind, tidal, and water energy to wood, coal, gas, oil, solar, and nuclear sources of fuel and power [7]. Agricultural sector has become more energy-intensive in order to supply more food to increasing population [8]. Currently, considerable fossil energy is used in agricultural productions. Breeding of higher-yielding plant varieties, increases in the number of seeds planted per hectare, more intensive use of fertilizers and pesticides, irrigation systems and farm machines depend on the use of significant amounts of fossil energy [9]. Agricultural productions can be enhanced by finding ways to augment solar energy using human, animal, and fossil energy power [3]. Indeed, a combination of the both renewable and non-renewable energies including solar, fossil, human and other sources of energies is needed to a successful agricultural system [10]. Energy use in agriculture can be divided into direct and indirect, renewable and non-renewable [11]. Direct energy refers to the any sources of energies, i.e. diesel fuel, gasoline, electricity, natural gas, animal and human power which use directly in the farm during crop production. Indirect energy is used off the farm in manufacturing, packaging and transporting farm machines, fertilizers, chemicals, irrigation systems, seed and so on [12]. Most of studies on energy consumption in agriculture consider seed, manure, animal and human power as renewable sources of energies [13-17]. However, it seems that these sources of energies are not totally renewable since they use both the sources of renewable and non-renewable energies. Demand for energy is not only increasing in the agricultural sector, but in all other sectors that involve human activities. Cropping pattern, farm activities and level of technology are some of the factors that define the rate of energy requirements in agriculture. Over time, the risk of energy scarcity is getting more severe. In such a situation, a sustainable agricultural system can be defined as a system with the lower energy input which is more sustainable from the environmental and the economic points of view.

In the coming decades the world faces the challenge to make a transition to sustainable energy use patterns in order to save fossil fuels for future generations and to reduce the negative impacts of burning fossil fuels on the environment [18]. The scarcity of energy resources and the significant dependency of agriculture on such resources have led a lot of researchers to evaluate the energy use of different crops in different regions. Energy and environmental security are major problems facing our global economy [19]. Energy balance is essential in corn production since it is a good source of food and biofuel specially bioethanol. Accordingly, optimum and sustainable energy utilization is a challenging issue in corn cultivation in a large number of regions worldwide. For instance, the energy input for corn production in Canada [20], Wisconsin and Germany [21] is 1.54, 1.43 and 2.16 MJ/Kg, respectively. It is higher in some countries like India and Thailand by 1.2-3 times [11,22].

Corn is a strategic crop in Iran as it is a main feeding source in the poultry production and therefore a critical input in the poultry industry. The total annual cultivated area is around 300000 ha with the average yield by 5500-7500 Kg/ha. The total country's need is estimated at four million tons per year of which 30-45% is imported [23]. Energy demand is increasing for most of crops including corn as a summer crop in Iran, and this demand is not sustainable in relation to opinions of many experts. For instance, fertilizer demand increased by 30 times during 1960-2003 (from 100 to 3000 thousand tons), and it will be reached to 6200 thousand tons by 2017-2018 [24]. Also, chemical use is 20-22 thousand tons per year which is 13 times more than the average consumption in the world [25].

Accordingly, the main objective of this study is to determine whether the amount of energy input for corn production is sustainable and how the energy use and corn cultivation sustainability can be improved. To reach the objective, we will first assess the range of energy input in the region, then, different groups of farmers will be determined according to their energy use by application of non-hierarchical cluster analysis. Afterwards, corn farming sustainability will be evaluated by using multi-fuzzy modeling. Finally, DEA will be used to highlight efficient and inefficient farmers and improve corn farmers' efficiency.

1.2. Why using fuzzy modeling and DEA technique?

Fuzzy set theory was developed by Zade in 1975 [26], and has been successfully applied in many fields of study afterwards [27-31]. The theory may be regarded as an extension of classical set theory, which is based on bi-valued logic; i.e., in or out. A fuzzy set, on the contrary, is a multi-valued logic defined as membership functions that represent the degree which the specified value belongs to the set [32]. Fuzzy logic is a very flexible technique that allows integrating different types of information (qualitative and quantitative) to formalize conclusions [33]. The use of fuzzy logic is based on the idea that the line between sustainability and unsustainability (or acceptance and rejection) of an agricultural practice is not clear but rather blurred or fuzzy [34]. Also, different types of subjects (positive or negative) can be combined by fuzzy modeling. Fuzzy models are designed for complicated and ill-defined problems such as sustainability assessments. Since the term "sustainability" is a concept with some sort of vagueness and uncertainty in assessment, fuzzy modeling can be used to overcome the uncertainty [32]. Accordingly, fuzzy modeling as a powerful tool has been used to evaluate different aspects of sustainable agriculture; i.e. farm machinery and tillage systems [35,36], fertilizer and herbicide application [37], energy utilization and sustainability [38-40], and postharvest technologies [41]. Nonetheless, a large number of studies on energy inputs for crop production have used a computational framework without any modeling [42,11,22,43-48].

The fuzzy modeling applied in this study regards two main aspects: engaging experts' knowledge and experience, and determining a reasonable index that displays the actual status of corn production sustainability from the energy input point of view. Furthermore, in order to evaluate the energy use status of corn production from an efficiency point of view, Data Envelopment Analysis (DEA) technique is used. The DEA technique is a non-parametric method, supplies wealth information in the form of estimates of inefficiencies in both inputs and outputs for every DMU (Decision Making Unit; i.e. farmers in this study) [49]. Both the DEA and fuzzy DEA have been used mainly in accounting, management and economic and fewer in other sciences like agriculture. Most researches in agriculture only evaluated technical and some other types of efficiencies [50-57]. As far as we know, this study is the first attempt to combine fuzzy and DEA modeling in such a way that uses outputs from fuzzy models as the main inputs in DEA models. Consequently, approaching both sustainability and efficiency is expected.

2. Methodology

This study was carried out to evaluate energy consumption of corn production in the farming year 2010 in the central region of the Fars province, Southwest Iran. The region covers 40000 hectares and consists of two towns (Marvdasht and Pasargad), and five counties; namely Seyedan, Houmeh, Rahmat, Markazi and Ramjerd. The province was chosen since it is the top corn producer in the country and presents more than 30% of the total corn production [23]. The province is located within $27^{o}\ 03^{'}$ and $31^{o}\ 40^{'}$ north latitude and $50^{o}\ 36^{'}$ and $55^{o}\ 35^{'}$ east longitude.

The central region of the province has a moderate temperature in summer [58] ranging from 15 to 37 degrees centigrade. Due to this suitable weather and the existence of the medium to high irrigation water and fertile soil, the region has the highest average yield in the country and produces 35-50% of total corn of the province. Therefore, sustainable and efficient corn production in this region could have a significant effect on the country's corn production independency.

Eighty nine farmers were chosen through a simple random sampling without replacement. The desired sample size was calculated by Equation 1 [59]:

$$n = \frac{[\frac{t.s}{r.y_N}]^2}{[1+(1/N)[\frac{t.s}{r.y_N}]^2]} \quad (1)$$

Where:

- n is the required sample size;
- N is the number of holdings in target population;
- S is the standard deviation of the sample;
- y_N is the mean of the sample;
- t is the reliability coefficient (2.576 which represents the 99% reliability);
- r is the permissible difference between actual and calculated mean (0.03 in this study).

S and y_N were calculated by a primary sample consists of 50 farmers as 43441.57 and 4980.43 MJ/ha, respectively. Finally, using Equation 1, 88.61 (rounded to 89) farmers were chosen from the total 1035 (N) corn farmers.

Two types of questionnaires were designed, one to collect the information regarding to energy input in the farms, and the other to set up the fuzzy models as discussed in the following sections.

2.1. Energy use analysis

A 6-page questionnaire was designed to gather data on the energy use by corn farmers. Since most of the farmers were illiterate or had only elementary literacy, five agricultural engineers were asked to collect the information via face to face interviews with the farmers. The questionnaire consisted of the questions which were asking about seed, fertilizer and chemical consumptions, soil type, the number of applied farm operations and types of farm machines and equipments etc.

The amounts of the applied inputs, i.e. fertilizers, chemicals, human power and seed were calculated per hectare, and multiplied by their energy equivalents (Table 1) to convert them to energy unit MJ/ha. Fuel as a direct and machinery as an indirect source of energy are two main energy consumers in farm operations. In order to measure the energy input in the form of fuel and machinery, the following factors were considered: "machine type", "speed of operation", "farm slope" and "soil texture". Fuel consumption by farm machines as a direct source of energy was calculated by Equation 2 [60]:

$$Q_{avg} = 0.223 \times P_{pto} \quad (2)$$

Where:

Q_{avg} = average diesel consumption; gal/h as multiplied by 3.78 to convert it to L/h.

P_{pto} = maximum PTO power (hp)

The amount of energy used by machinery production as an indirect energy input was estimated by Equation 3 [61]:

$$EID = TW \times CED \times h \times RU/UL \quad (3)$$

Where:
EID = indirect energy used for machinery production, MJ/ha;
TW = total weight of the specific machine, kg;
CED = cumulative energy demand for machinery, MJ/kg;
UL = wear-out life of machinery, h;
h = specific working hours per run, h/ha;
RU = runs, number of applications in the considered field operation.

Another two essential energy consumers are electricity as a direct and irrigation as an indirect energy inputs to deliver water to the farms. Electricity shows the amount of energy input for pumping water as a source of direct energy. Irrigation presents indirect energy which is used in manufacturing of water pumps, barriers and water canals. Since the irrigation energy was directly calculated as 20% of electricity, it was not considered in the fuzzy and DEA models. The energy output-input ratio, energy productivity and specific energy are the main indices to show energy efficiency. The indices are formulated as below [11]:

Energy ratio: energy output/energy input (4)
Specific energy: energy input/grain yield output (MJ/kg) (5)
Energy productivity: grain yield output/energy input (kg/MJ) (6)
Net energy gain: energy output-energy input (MJ/ha) (7)

These indices show the status of a system according to two aspects: the total energy input and the yield (or energy output). However, it cannot be found out whether the system is sustainable or how it would be improved. For instance, a system may be reached to a better energy ratio by 2 times more yield production and 1.5 times more energy input. In spite of more energy ratio, more energy input may be resulted in lower sustainability. Therefore, the researchers needed to use other scientific methods like fuzzy and DEA to evaluate the sustainability and efficiency of the systems, more carefully. Additionally, the types of energies, i.e. direct, indirect, renewable and non-renewable are not embedded in these indices. A useful index would be defined as the ratio of renewable to non-renewable energy inputs. This index shows that to what extent a system rely on renewable or non-renewable sources of energies. Although the category of the direct and indirect energy shows the source of energy from these two aspects, seemingly there is no significant relationship between these two categories and sustainability.

2.2. Non-hierarchical cluster analysis

Cluster analysis is a multivariate method which aims to classify a sample of subjects (or objects) on the basis of a set of measured variables into a number of different groups such that similar subjects are placed in the same group [64]. Accordingly, in order to assess different attitudes in energy utilization, non-hierarchical cluster analysis (often known as k-means clustering method) was used. As the name implies, this method exhibits a group of farmers with similar energy applications. For instance, a group of farmers with low energy inputs in the form of fertilizer and chemical and high in the form of fuel. Non-hierarchical cluster analysis tends to be used when large data sets are involved [65].

Since determining the number of appropriate clusters (K) is a challenging issue in this method, a combination of K-means and MANOVA was applied to distinct proper K. By

MANOVA, all energy parameters were considered as variables and different Ks (2, 3, etc.) as treatments. The K with minimum Wilks' coefficient and maximum F was chosen as the best solution, since it represented maximum difference between clusters and minimum difference within a cluster.

2.3. Multi-fuzzy modeling

The basics of fuzzy sets has already discussed in many books and papers [26,66-69]. Since there were numerous energy parameters that should be taken into account, we developed three multi-fuzzy models as primary models. With such an approach, defining fuzzy rules would be much easier and therefore the outputs of models would be improved. As shown in Fig. 1, the three primary models are:

1. Model F ("Fertilizer") with three input variables: all types of fertilizers and yield are considered in this model. Fertilizers were divided to two types and defined as two input variables; namely NPPM (nitrogen, phosphorous, potassium and micronutrients) and Ma (manure).
2. Model M ("Machinery") with four input variables: machinery, fuel, seed and yield are applied in this model.
3. Model C ("Chemical") with four input variables: chemical, electricity, human power and yield are the inputs of this model.

One sustainability index came from each model. These three primary sustainability indices were combined into a secondary model FMC (combination of models F, M and C) as the main input variables to reach a total sustainability index as the main output. In order to define the types and the ranges of membership functions based on the experts' knowledge, we chose almost all of available agricultural experts in the region who were familiar with the farming condition in the region from both technical and cultural points of view. Accordingly, 26 experts were chosen. The experts held bachelor, master of science or doctoral in agriculture, and were familiar with the energy and sustainability issues and some with the fuzzy modeling. The experts were asked to:

1- define the labels (linguistic values)
2- determine the ranges of each value labels
3- express fuzzy if-then rules

As shown in Fig. 2, the experts have defined a triangular and shoulder shape for the fuzzy sets. Almost all the experts (97%) preferred to set-up four linguistic values for input linguistic variables; namely "low, medium, high, and very high". The values for output variables (sustainability indices) and the FMC model were determined in five levels according to International Union for Conservation of Nature and Natural Resources (IUCN) [70] as very low, low, medium, high and very high. Each expert determined the ranges of linguistic values based upon his/her specialty and background. The mean of all the ranges introduced by the experts was calculated to construct the models using Matlab Fuzzy Toolbox (version 7.6). Fig. 2, also shows the structure of (for instance) Model C which includes electricity, chemical, human power and yield as the inputs, and the sustainability index C as its output. Also, the figure displays the ranges of functions for chemical energy that defined by the experts as [0 0 210 310], [190 410 710], [462 757 967] and [810 910 1300 1300] for the levels "low, medium, high and very high", respectively.

If-then rules in a fuzzy model are defined based on input variables and their linguistic values. For instance, all possibilities for Model F is 64 since it has three input variables as NPPM, Ma and yield that each variable has four linguistic values as low, medium, high and very high. Holding the same procedure, the total number of all possible if-then rules for the models are estimated as follows:

Model F: 4*4*4 = 64
Model M: 4*4*4*4 = 256
Model C: 4*4*4*4 = 256
Model FMC: 5*5*5 = 125

All the above possible combinations of the if-then rules were prepared by means of a simple programming in Matlab with an empty column as output. To finalize the definition of if-then rules, all experts were asked to fill out the output column. After gathering the data from the experts, the designed models were presented to the experts for their final revision. At last, all the experts confirmed the models' set-ups.

2.4. DEA technique

For assessing energy consumption efficiency of each farmer (DMU_s)[*], DEA[†] technique was used. CCR, BCC and SBM[‡] models were analyzed using DEA Excel Solver. DEA was used by seven energy inputs, i.e. machinery, fuel, fertilizer, human power, seed, chemicals and electricity. DEA was employed three times with different outputs. First, yield as the output, then sustainability indices from the fuzzy models F, M, and C as the outputs, and at last, both the yield and sustainability indices as the outputs. The best results came from DEA when yield and sustainability indices were chosen as the outputs as discussed in section 3.2.

2.4.1. Technical efficiency

Technical efficiency is the efficiency in converting inputs to outputs. It exists when it is possible to produce more outputs with the inputs used or to produce the present level of outputs with fewer inputs. According to Cooper et al. [71], it can be stated as the ratio of the sum of weighted outputs to the sum of weighted inputs as described in Formula 8:

$$TE_j = \frac{u_1 y_{1j} + u_2 y_{2j} + \dots + u_n y_{nj}}{v_1 x_{1j} + v_2 x_{2j} + \dots + v_m x_{mj}} = \frac{\sum_{r=1}^{n} u_r y_{rj}}{\sum_{s=1}^{m} v_s x_{sj}} \quad (8)$$

where 'x' and 'y' are input and output, and 'v' and 'u' are input and output weights, respectively, 's' is number of inputs (s = 1,2,. . .,m), 'r' is number of outputs (r = 1,2,..,n) and 'j' represents j^{th} DMUs (j = 1,2,. . .,k). For solving Equation (8), the following linear program (LP) was developed by Charnes et al. [72], which called CCR model (Formulas 9-13):

$$\text{Max:} \quad \theta = u_1 y_{1i} + u_2 y_{2i} + \dots + u_r y_{ri} \quad (9)$$

$$\text{Subject to:} \quad v_1 x_{1i} + v_2 x_{2i} + \dots + v_s x_{si} = 1 \quad (10)$$

$$u_1 y_{1j} + u2 y_{2j} + \dots + u_r y_{rj} \leq v_1 x_{1j} + v_2 x_{2j} + \dots + v_s x_{sj} \quad (11)$$

$$u_1, u_2, \dots, u_r \geq 0 \quad (12)$$

$$v_1, v_2, \dots, v_s \geq 0, \text{ and (i and j = 1, 2,\dots, k)} \quad (13)$$

where θ is the technical efficiency and i represents i^{th} DMU.

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[*] . DMU: Decision Making Unit
[†] . DEA: Data Envelopment Analysis
[‡] . CCR: Charnes, Cooper and Rhodes; BCC: Banker, Charnes and Cooper; SBM: slack based measure.

2.4.2. Pure technical efficiency

In 1984, Banker, Charnes and Cooper introduced a model in DEA, which was called BCC model to draw out the technical efficiency of DMUs [73]. The calculation of efficiency in BCC model is called pure technical efficiency and can be expressed by Dual Linear Program (DLP) as:

Max: $Z = uy_i - u_i$ (14)

Subject to: $vx_i = 1$ (15)

$-vX + uY - u_o e \leq 0$ (16)

$v \geq 0, u \geq 0$ (17)

Pure technical efficiency shows the DMU management [52]. Generally, the CCR-efficiency does not exceed BCC-efficiency [49]. The result of the BCC model shows that how many percent of energy used have contributed to the output. Since we tried to decrease energy input, input-oriented was used for the CCR and BCC models in this study. In such a way, the models reduce the inputs as much as possible and conserve the level of outputs.

2.4.3. Scale efficiency

Technical inefficiency is caused by the operation of the DMU itself (pure technical efficiency) or by the disadvantageous conditions under which the DMU is operating (scale efficiency). According to Cooper et al. [71], scale efficiency shows the effect of conditions on the DMU inefficiency and is defined as:

Scale efficiency = Technical efficiency / Pure technical efficiency (18)

The conditions for a firm are considered as the firm size, the number of clerks and so on [74]. In agricultural systems, the conditions can be regarded as the weather, the compatibility of farm machines and equipments with the farm sizes and soil conditions, appropriate irrigation systems and water availability [52].

2.4.4. SBM

As the CCR and BCC models calculate efficiency scores considering inputs or outputs separately, the SBM model has been developed to consider both inputs and outputs simultaneously [75]. Therefore, in our study, this model tries to determine efficient farmers with regard to minimum inputs (energy parameters) and maximum outputs (yield and sustainability indices). The SBM model is formulated as below [71]:

MAX: $\sum_{i=1}^{m} S_i^{-} + \sum_{r=1}^{s} S_r^{+}$

(19)

Subject to: $\sum_{j=1}^{n} \lambda_j x_{ij} + S_i^{-} = x_{io} \qquad i = 1,2, \dots, m;$ (20)

$\sum_{j=1}^{n} \lambda_j y_{rj} - S_r^{+} = y_{ro} \qquad r = 1,2, \dots, s;$ (21)

$\lambda_j, S_i^{-}, S_r^{+} \geq 0$ (22)

Where S_i^- and S_r^+ are excess and shortfall in inputs and outputs, respectively.

3. Results and discussion

3.1. Energy use analysis

The results of the energy use analysis for the corn production are given in Table 2. Column Total in this table shows the result of all farmers (89 farmers) before clustering. The result of non-hierarchical clustering by combination of K-means and MANOVA clears that the best number of clusters (k) is two; i.e. 47 and 42 farmers in the first and the second cluster respectively.

The total input and output energy for the corn production are 42953.27 and 108150.54 MJ/ha, respectively. More than 85% of energy input is used by the three following main energy consumers: fertilizers, electricity and diesel fuel. Specific energy and output-input energy ratio are 5.860 MJ/kg and 2.537, respectively. In compare to four countries, i.e. India, Thailand, U.S. and Italy our farmers use the most energy to produce corn (Table 3). The remarkable point is that the studied farmers consume energy 3-4 times more than Thailand and India. Although the average yield is more than these countries, all the energy indices (i.e. energy productivity, specific energy, net energy gain and output-input energy ratio) are lower as a consequence of high energy input. Our farmers use much more energy for fertilizers, diesel fuel and electricity by 3.5-13 times in compare to these two countries. The farmers' energy use of diesel fuel and fertilizers are almost similar to U.S. and Italy. In spite of these similarities, the mean yield in Iran's farms is lower than U.S. and Italy by 1642.82 and 4142.82 kg/ha, respectively. However, the farmers use much more electricity that cause to difference in energy input of these three countries.

Clustering displays different attitudes on energy consumption amongst the farmers who, in cluster 2, use around 2500 MJ/ha more energy than those in cluster 1. As discussed most studies on energy consumption in agriculture consider seed, manure, animal and human power as renewable sources of energies. However, these sources of energies are not totally renewable. With this regard, our farmers use no renewable energies in corn production which would result in low sustainability of agricultural system [77] in the region. Statistical analysis reveals that there are significant differences ($P<0.05$ or $P<0.01$) between the two clusters on the amount of energy in some inputs such as seedbed preparation and planting (machinery and fuel), human power, seed and chemicals. However, there are great differences (by 150-1600 MJ/ha) in three inputs; i.e. seedbed preparation (machinery and fuel), fertilizer (nitrogen) and chemicals. The typical farm operations in cluster 2 are: plowing with moldboard plow, three times disking, three times land leveling and finally planting. In addition to high number of farm operations, most of farmers in this cluster use obsolete heavy equipments with low or high power tractors that result in noticeable difference in fuel energy use for seedbed preparation by around 1000 MJ/ha between the two clusters. Nonetheless, the farmers who are in cluster 1, manage their farm time schedules and reduce the number of disking and land leveling by in time farm operations that result in less energy use for two inputs, i.e. machinery and fuel. Moreover, they use more matched equipments with their tractors that result in higher scale efficiency scores for this cluster as discussed in the next section.

Cluster 1, compared to cluster 2, consumes much less fertilizers and much more chemicals. However, around 40% of energy input in both the clusters belongs to "fertilizers". Although nitrogen is more dangerous for the environment due to its mobility compare to other fertilizers, it accounts for 93% of the total fertilizers. In spite of high increase in the prices of energy since

2007 in Iran, as there is no suitable law to restrict the use of agricultural inputs, the farmers tend to consume energy more and more, especially in the forms of fertilizers and chemicals. Banaeian and Zangeneh's study approved that the average of total energy input of corn production in Iran increased by 22.66 GJ/ha during 2001-2007 [14]. Around 1-3% of farmers use farm fertilizer and chemical applicators. Traditional application of these inputs by labors on the one hand results in higher consumptions and wastes, and lead to lower efficiency and sustainability on the other hand. The share of electricity is one third of the total energy input since 90-99% of farmers in both the clusters use furrow irrigation systems in addition to improper farm slope and soil smoothness. However, the soil condition is better in the farms of cluster 1 that results in lower electricity energy input. As Iran has recently encountered chronic droughts, farmers' financial problems are the main inhibitor toward using modern irrigation systems.

Correlation analysis shows that linear relationship between the total fertilizers, nitrogen, chemicals, total energy input and yield are 0.765, 0.83, 0.74 and 0.74 in cluster 1, respectively. Furthermore, there are weaker correlation coefficients between the total fertilizers, nitrogen, total energy input and yield in cluster 2 (0.499, 0.547 and 0.33, respectively). The weaker coefficients in cluster 2 demonstrate that those farmers who are in this group do not conduct soil sampling to estimate the correct amounts of fertilizers or other inputs. As a consequence, they use and waste the inputs carelessly that results in their low sustainability of corn production. Also, there is a great gap (by 5000-10000 MJ/ha) on energy input among the farmers with the same farming circumstances, i.e. the same region, the weather, the water and the soil type. Since 50% of this energy difference belongs to nitrogen, shows that there is a chaos on using this input. Also, in spite of similar farming situations, this gap is as a consequence of using unmatched farm equipments and tractors, improper irrigation systems and wasting chemicals and specially fertilizers.

3.2. Sustainability and efficiency analysis using multi-fuzzy models and DEA

Sustainability analysis by application of multi-fuzzy models reveals that the farmers use energy in the low to medium levels of sustainability (Table 4). The sub-models F and C show that the farmers act more unsustainably in utilization of fertilizers and chemicals. Model M displays that the status of using energy for machinery, diesel fuel and seed are better than the other terms of energy inputs. However, the maximum indices come from the main FMC model and the sub-model C by 0.580 and 0.521, respectively that belong to some farmers in cluster 1. The FMC model indicates that the farmers in cluster 1 produce corn in a more sustainable energy manner holding the average sustainability index equal to 0.256. Nevertheless, all the outputs' means from FMC are in the ranges of very low to medium which should be considered as alarming ranges for corn producers, agricultural experts and governmental decision makers if sustainability is a goal.

As discussed earlier, DEA is applied in three ways with the following outputs: first, with yield, second, with sustainability indices, and finally with both the yield and sustainability indices. The results of DEA reveal that with the yield or sustainability indices as outputs, those with high yield and low sustainability indices might be chosen as efficient farmers and vice versa. But by using the yield and sustainability indices as outputs, those with medium or high yields and sustainability indices could be chosen as efficient and frontiers farmers. Therefore, both of these outputs are entered to the DEA models. The results of technical, pure technical, scale and slack based measure efficiencies show that around 50-60% and 40-50% of the efficient farmers are in cluster 1 and 2, respectively (Table 5). The yield and sustainability indices of this group are 6700-7500 kg/ha and 0.35-0.58, respectively. Furthermore, the results also show that around 15% of CCR-inefficient farmers can improve and move toward the BCC-efficient frontiers.

The percent of the high scored technically efficient farmers, by 90% or more, with a great difference are 72.34% and 42.85% in cluster 1 and 2 respectively. Since the technical inefficiency would be caused by the management (pure technical efficiency) or the conditions under which the DMU is operating (scale efficiency), this difference can be analyzed in more details. As described earlier, the conditions in farming systems can be observed as weather, farm machinery, soil and water etc. Because the study site covers the same weather, and almost the same soil and water condition, we focus on the availability of appropriate farm machines and irrigation systems to find the reasons of scale inefficiencies. Pure technical and scale efficiencies display that this difference is due to the lower scale efficiency in cluster 2. Near to 70-80% of the farmers in both the clusters are purely technical efficient, reveals that the farmers' farm management to simply prepare inputs and so on is not bad. Approximately, all the experts confirm the result of the BCC model since they believe that the corn farmers have enough experience from the management point of view. Nonetheless, they describe that the farmers need to promote their agricultural basic knowledge especially in the application of inputs at the right time, quantity and quality. Although the average farms' size is small that result in low scale efficiency scores, most experts believe that the existence of the old and obsolete farm machines are the main factors of this problem. Also, they emphasize that the more scale efficient farmers in cluster 1 is due to availability of new and suitable farm machines and especially skilled farm machinery operators. To confirm this idea, the distribution of the farmers who are in cluster 1 is inspected. Since the most scale efficient farmers have a good access to new and suitable farm machines and essentially skilled operators, it seems that the role of farm machines is more than the irrigation systems to promote the scale efficiency of the corn production in this region. However, the suitable irrigation system is another important factor to improve the scale efficiency. Therefore, the purely technical inefficient farmers should promote their agricultural knowledge and experience and apply a better management. Also, scale inefficient farmers should use irrigation systems and proper farm machines which are more matched with their farm size that result in the energy input reduction by 5000-10000 MJ/ha as discussed in section 3.1.

SBM is more practical in this study since it condenses inputs and increases outputs to determine the efficient farmers. SBM also reveals that most of the inefficient farmers should reduce their use of energy by 45-65% and enhance the yield and sustainability indices by 0-15% and 0-400%, respectively. SBM solution indicates that the most reduction should be applied in fertilizers. It confirms that the farmers use this input very extravagantly.

4. Conclusion

This study used a combination of fuzzy logic and DEA models to evaluate the energy use sustainability and efficiency of the corn production and its energy use improvement. The results revealed that specific energy and output-input energy ratio are 5.860 MJ/kg and 2.537, respectively. However, these indices show the farming situation from only input and output energy points of view not sustainability or the types of energy input like renewable or non-renewable. Using fuzzy models, we found that the corn production is in the ranges of low to medium levels of sustainability. DEA revealed that sustainability indices promotion is achievable by reduction in energy input by 45-65%. Sustainability of the corn cultivation can be promoted by making appropriate energy policies and laws for agricultural sector with regard to different regions and cropping systems. Approving prohibiting law on fertilizers and chemicals applications especially nitrogen is essential as it is accounting for 93% of all the fertilizers' energy input, and the most reduction should be applied in this part. Also, it seems that the introduction of precision fertilizer and chemical applicators are very beneficial for some crops such as corn as a fertilizer-intensive crop. Moreover, changing current tillage and irrigation methods toward conservation systems like reduce or no tillage and sprinkler or drip irrigation systems is necessary in order to decrease the energy input in addition to water and air quality, food safety and soil fertility. Due to lack of an accurate weather prediction system, the farmers cannot manage their farms suitably. Some essential infrastructures such as powerful weather organization and on time announcement are needed to accurate farm management and timely farm operations.

Since DEA introduces an efficient to an inefficient farmer as a reference, we observed that the majority of the efficient framers, who are selected as the reference sets, belong to cluster 1. The efficient farmers, who are determined by DEA, cultivate corn in the medium to high levels of sustainability, therefore, if inefficient farmers follow them, sustainability indices will be promoted to these levels. Indeed, by using a combination of fuzzy modeling and DEA technique, agricultural sustainability would better be estimated and could improve up to level of sustainability which is being done by the efficient farmers. In other words, it seems that for more (very high) sustainable corn production, the whole society of farmers including both the efficient and inefficient, must amend their trends and reduce input energy as much as possible. Yet, the evaluation of optimum level of the energy utilization remains as a main issue for future studies. Also, the definition of new indices like ratio of renewable to non-renewable energy inputs is recommended. With such indices the sustainability of agricultural systems would be analyzed even more carefully from renewability of energy inputs point of view.

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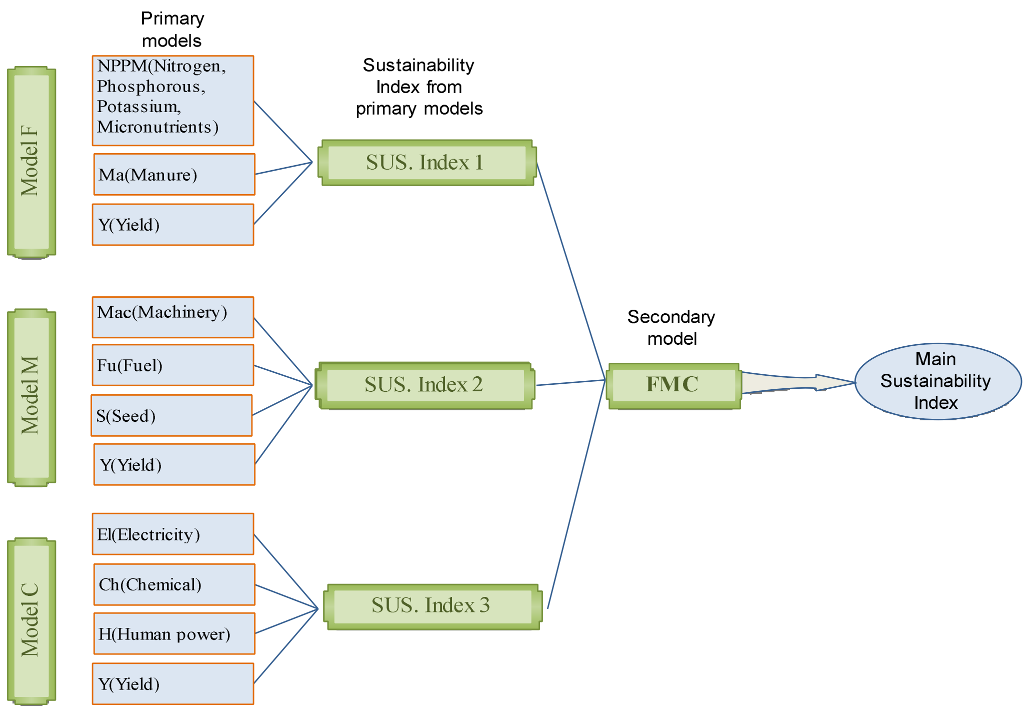

Fig. 1. Schematic diagram of primary and secondary models.

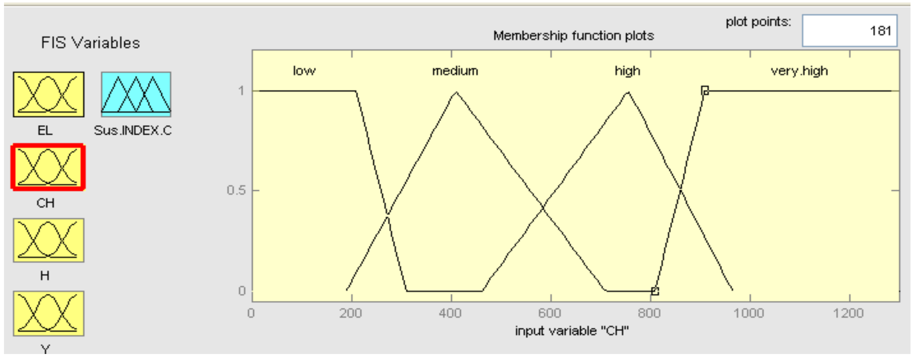

Fig. 2. The structure of fuzzy model C.

Table 1: Energy equivalents of inputs and outputs in agricultural production.

Input(unit)	Energy equivalent(MJ/unit)	Reference
Liquid chemical(L)	102	[62]
Granular chemical(kg)	120	[62]
Human power(h)	1.96	[6]
Machinery(kg)	62.7	[13]
Nitrogen(kg)	66.14	[63]
Phosphorus(kg)	12.44	[63]
Potassium(kg)	11.15	[63]
Manure(kg)	0.3	[13]
Zinc sulphate(kg)	20.9	[13]
Diesel(L)	56.3	[13]
Corn seed(kg)	14.7	[6]

Table 2: Energy used status for corn production.

	Average (MJ/ha)		
	Total	Cluster 1	Cluster 2
1-Machinery	1403.236(3.27%) *	1358.745(3.25%)	1453.024(3.28%)
1-1- Seedbed preparation	465.629[33.18%] **	389.255[28.65%]	551.095[37.93%]
1-2- planting	275.910[19.66%] **	310.660[22.86%]	237.024[16.31%]
1-3- fertilizer application + spraying	149.517[10.66%] n.s	163.064[12.00%]	134.357[9.25%]
1-4- harvesting	512.180[36.50%] *	495.766[36.49%]	530.548[36.51%]
2- Diesel fuel	7710.709(17.95%) n.s	7599.455(18.18%)	7835.207(17.71%)
2-1- Seedbed preparation	3602.944[46.73%] **	3137.468[41.29%]	4123.833[52.63%]
2-2- planting	2561.784[33.22%] **	2921.898[38.45%]	2158.800[27.55%]
2-3- fertilizer application + spraying	261.294[3.39%] n.s	271.477[3.57%]	249.900[3.19%]
2-4- harvesting	1284.687[16.66%] n.s	1268.613[16.69%]	1302.674[16.63%]
3- Fertilizers	16736.110(38.96%) *	15974.031(38.21%)	17588.914(39.76%)
3-1- Nitrogen	15498.317[92.6%] *	14731.003[92.22%]	16356.978[93.00%]
3-2- Phosphorous	484.854[2.90%] n.s	519.217[3.25%]	446.400[2.54%]
3-3- Potassium	191.011[1.14%] n.s	160.106[1.00%]	225.595[1.28%]
3-4- Manure	537.079[3.21%] n.s	538.298[3.37%]	535.714[3.05%]
3-5- Other (zinc sulphate, iron, etc.)	24.849[0.15%] n.s	25.406[0.16%]	24.226[0.14%]
4- Human Power	413.915(0.96%) **	356.596(0.85%)	478.059(1.08%)
5- Seed	354.121(0.82%) **	364.685(0.87%)	342.300(0.77%)
6- Chemicals	599.377(1.4%) **	711.595(1.70%)	481.689(1.09%)
7- Electricity	13113.170(30.53%) n.s	12866.585(30.78%)	13389.110(30.27%)
8- Irrigation	2622.634(6.11%) n.s	2573.317(6.16%)	2677.822(6.05%)
- Total input energy	42953.27(100%) *	41805.009(100%)	44238.235(100%)
- Direct energy	21237.794(49.44%)	20822.636(49.81%)	21702.376(49.06%)
- Indirect energy	21715.479(50.56%)	20982.373(50.19%)	22535.859(50.94%)
-Total output energy	108150.54	108373.091	107901.500
- Output-input energy ratio	2.537	2.592	2.439
- Energy Productivity (kg/MJ)	0.173	0.176	0.166
- Specific energy(MJ/kg)	5.860	5.682	6.024
- Net energy gain(MJ/ha)	65197.270	66568.083	63663.265
- Yield(kg/ha)	7357.18 n.s	7372.319	7340.238

* , **: Show significant difference between cluster1 and 2 in 0.05 and 0.01 probability level, respectively.

Table 3: Energy used status for corn production in some other countries.

	Average (MJ/ha)				
	Iran	India [11]	Thailand [22]	Italy [48]	U.S. [76]
1-Machinery	1403.236	114.64-893.95	------	------	1394.2
2- Diesel fuel	7710.709	1033.55	10050.4	6600	5895.01
3- Fertilizers	16736.110	1734.10-4019.64	[5713.4]	17700	[12903.70]
3-1- Nitrogen	15498.317	------	4730	14600	10383.26
3-2- Phosphorous	484.854	------	854.2	1000	1373.27
3-3- Potassium	191.011	------	129.2	2200	1147.18
3-4- Manure	537.079	1141.09-3633.61	------	------	------
3-5- Other (zinc sulphate, iron, etc.)	24.849	------	------	------	------
4- Human Power	413.915	1592.42-2572.99	46.9	------	1934.3
5- Seed	354.121	569.17-1564.46	290.3	------	2177.14
6- Chemicals	599.377	------	667.6	700	3768.12
7- Electricity	13113.170	------	------	------	142.35
8- Irrigation	2622.634	51.74	------	4100	1339.78
- Total input energy	42953.27	4412.61-10486.51	12638.9	29700	31275.4
- Direct energy	21237.794	2785.4-7259.5	------	------	------
- Indirect energy	21715.479	1627.21-3227.01	------	------	------
-Total output energy	108150.54	56247.6-77663.10	66610.6	218500	132353.12
- Output-input energy ratio	2.537	7.41-12.74	5.3	7.36	4.23
- Energy Productivity (kg/MJ)	0.173	0.14-0.25	------	------	------
- Specific energy(MJ/kg)	5.860	3.98-6.93	------	[2.5]	[3.48]
- Net energy gain(MJ/ha)	65197.270	51834.99-67176.59	------	------	------
- Yield(kg/ha)	7357.18	1108-1513	4531.33	11500	9000

Table 4: Sustainability indices from multi-fuzzy models for corn production.

Farmers	Fuzzy Models											
	Model F			Model M			Model C			Model FMC (Main)		
	mean	min	max	mean	min	max	mean	min	max	mean	min	max
Total	0.25	0.08	0.45	0.316	0.11	0. 353	0.307	0.10	0.521	0.170	0.077	0.580
Cluster 1	0.25	0.12	0.45	0.338	0.11	0. 353	0.250	0.14	0.521	0.256	0.11	0.580
Cluster 2	0.215	0.08	0.38	0.289	0.11	0.26	0.268	0.10	0.281	0.10	0.077	0.25

Table 5: Frequency distribution of corn growing farmers according to DEA models.

		Total	Cluster 1	Cluster 2
CCR model(TE)				
Efficient		37(41.57%)	25(53.19%)	16(38.09%)
Inefficient	> 90%	17(19.1%)	9(19.15%)	2(4.76%)
	81-90%	9(10.11%)	7(14.89%)	--
	71-80%	2(2.25%)	--	4(9.52%)
	61-70%	13(14.61%)	--	7(16.67%)
	< 60%	11(12.36%)	6(12.76%)	13(30.95%)
No. of farmers		89(100%)	47(100%)	42(100%)
BCC model (PTE)				
Efficient		49(55.1%)	29(61.7%)	22(52.38%)
Inefficient	> 90%	24(26.97%)	11(23.4%)	8(19.05%)
	81-90%	--	--	7(16.67%)
	71-80%	9(10.11%)	7(14.89%)	--
	61-70%	--	--	5(11.90%)
	< 60%	7(7.86%)	--	--
No. of farmers		89(100%)	47(100%)	42(100%)
SE				
Efficient		37(41.57%)	25(53.19%)	16(38.09%)
Inefficient	> 90%	15(16.85%)	10(21.28%)	4(9.52%)
	81-90%	12(13.48%)	1(2.13%)	7(16.67%)
	71-80%	6(6.74%)	2(4.26%)	5(11.90%)
	61-70%	11(12.36%)	4(8.51%)	2(4.76%)
	< 60%	8(8.99%)	5(10.64%)	8(19.05%)
No. of farmers		89(100%)	47(100%)	42(100%)
SBM				
Efficient		46(51.68%)	28(59.57%)	23(54.76%)
Inefficient	> 90%	1(1.12%)	1(2.13%)	--
	81-90%	3(3.37%)	--	2(4.76%)
	71-80%	3(3.37%)	6(12.76%)	--
	61-70%	2(2.25%)	1(2.13%)	5(11.90%)
	< 60%	34(38.2%)	11(23.40%)	12(28.57%)
No. of farmers		89(41.57%)	47(100%)	42(100%)