Cleaner Engineering and Technology 6 (2022) 100356

Contents lists available at ScienceDirect

Cleaner Engineering and Technology

journal homepage: www.sciencedirect.com/journal/cleaner-engineering-and-technology

Rice production energy efficiency evaluation in north of Iran; application of Robust Data Envelopment Analysis

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ARTICLE INFO

Keywords:
Data envelopment analysis (DEA) method
Conservatism
Energy efficiency
Imprecise data
Optimization

ABSTRACT

This paper aimed to identify the energy efficiency indices for rice producers in Golestan province, Iran. A non-linear Robust Data Envelopment Analysis (RDEA) model was applied based on seven energy inputs. The studied indices included energy efficiency, energy productivity, net energy efficiency, and water productivity. According to the results, all types of energy inputs and outputs were calculated 34,423.28 and 120,088.4 MJ/ha^{-1}, respectively. Consumed nitrogen (29.9%), diesel (21.0%), and water for irrigation (20.5%) have the highest values of energy inputs. The results showed that at the level of conservatism $\Gamma = 7$, half of the farmers are inefficient. The total optimum energy consumption was estimated to be 29,774 (MJ/ha^{-1}), meaning that 10.01% of the input energy can be stored. Reducing energy waste can even improve the viability of rice farms and help them more control over energy consumption.

1. Introduction

In most developed and even developing countries, the energy used to produce various agricultural products per unit area has been studied, and attempts have been made to optimize the energy system by calculating the energy efficiency index Khan et al. (2010). Another advantage of energy analysis is the determination of energy consumption at each stage of the production process. This will lead to providing a basis for protecting production resources as well as assistance in sustainable management and related policies (Taki et al., 2018a).

Iran is the 13th largest energy consumer in the world, and energy consumption in this country is five times the global average. Given the energy crisis, the efforts of countries and international communities are made to reduce energy consumption as much as possible. The agricultural sector is no exception. Recently, for sustainable agricultural production, effective energy use has become a requirement because it brings financial savings, conserves fossil resources, and reduces environmental damages. The amount of energy used depends on farming systems, planting and harvesting seasons, and agricultural conditions, while agricultural products and food supplies and distributions are stringently reliant on the energy consumptions. Energy input is an important indicator for sustainable development in the agricultural sector, due to the energy crisis and the greenhouse gas emissions resulting from excessive consumption of fossil fuels. Recently, most countries in the world attempt to calculate the energy input per unit for different production and determination performance indices, in order to increase the efficiency of energy utilization in agricultural mechanism (Mardani Najafabadi and Taki, 2020).

The Iranian government has emphasized this issue in several acts, the most important of which is the act on reforming the pattern of energy consumption. In Chapter 7 and Article 28 of this act, the Ministries of Oil and Agricultural Jihad and Department of Environment are explicitly responsible for determining the standard of energy consumption for each unit of agricultural cultivation area. This criterion of energy consumption in the agricultural sector should be developed according to climatic conditions and the type of product. Articles 29 and 30 of the same chapter also refer to the repair and replacement of worn and consumed machinery and equipment in this sector. Also, the Statute of Renewable Energy and Energy Efficiency Organization (Article 1-Note 1) emphasizes the promotion of energy productivity in various economic sectors, including agriculture. In Note 2 of the same article, the purpose of promoting energy efficiency is considered to be the optimal and rational use of energy; in such a way that energy loss can be

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https://doi.org/10.1016/j.clet.2021.100356
Received 23 April 2021; Received in revised form 19 November 2021; Accepted 3 December 2021
Available online 6 December 2021

Nomenclature

GHG	Greenhouse Gas
SD	Standard Deviation
DEA	Data Envelopment Analysis
DMU	Decision-Making Unit
IDEA	Interval DEA
FDEA	Fuzzy DEA
RDEA	Robust Data Evolvement Analysis
SE	Scale Efficiency
LP	Linear Programming
CCR	Charnes, Cooper, and Rhodes
BCC	Banker, Charnes, and Cooper
VRS	Variable Returns to Scale
CRS	Constant Returns to Scale
TE	Technical Efficiency
PTE	Pure Technical Efficiency
ESTR	Energy Saving Target Ratio

prevented without reducing social welfare and the level of national production.

One of the most important development acts in Iran is the act of the Sixth Five-Year Plan for Economic, Social and Cultural Development, which is mentioned in the section related to environment and natural resources (Section 9-Article 38) of the implementation of green management plan including optimal energy consumption management. Section 10 of Article 44 of this act also explicitly calls on the government to take the necessary measures to increase the added value of energy and to complete the value chain and reduce energy consumption for each production unit; For this purpose, a National Document of Iran's Energy Strategy has been developed, which considers one of the main challenges of energy resources in this country to be high energy intensity and low energy productivity in the agricultural sector.

In general, the main goals of creating energy acts for the Iranian agricultural sector can be summarized as follows:

- Improving consumption patterns and energy productivity in the agricultural sector for each crop and region
- Determining the standard of optimal energy consumption for each unit of cultivated area of crop in each region
- Determining the factors affecting the non-optimal energy consumption for each crop and region
- Determining alternatives or upgrading technology for energy-intensive inputs in the agricultural sector

The major food for a huge part of the world's population is rice (*Oryza sativa*). Rice is the main diet of Asia, Latin America, and Africa (Yuan and Peng, 2017). In Iran, rice has a special place in people's daily feed. Accordingly, mainly many agricultural activities belong to the rice crop. The total production of rice in 2015 was almost 2,746,500 tons in Iran, and the cultivated land was almost 575,000 ha. This year's annual rice production in Iran was more than 2.5 Mt (Jehad-Keshavarzi Organization, 2016). In this filed, after Mazandaran and Gilan, the Golestan province with 14% of total rice production, is one of the biggest producers in Iran. However, Iran has the second rank in terms of rice production (1.7 Mt per year) after the Philippines. Restrictions on rice cultivable lands, the semi-desert position of Iran, the lack of mechanization of farms, and the imbalance of domestic supply and demand are the important factors of this high amount of imports in Iran. Efforts to increase the production of rice crops are therefore needed immediately. On the other hand, energy analysis is essential for optimal resource management in order to improve agricultural production, thereby identifying efficient and economical production activities (Pashaei Kamali et al., 2017).

2. Literature review

Some studies on energy flow analysis for rice have been conducted in the northern provinces of Iran. For example, the study of Kazemi et al. (2015) analyzed the energy flow of rice in the provinces of Gilan, Golestan and Mazandaran. The results showed that the total energy input for rice production in Golestan province was 64,158.78 MJ ha−1 which was higher than other provinces, due to high energy consumption in diesel fuel style (46.44%).

AghaAlikhani et al. (2013) analyzed the pattern of rice energy consumption for both traditional and modern agriculture in Mazandaran province. Analysis of data showed that averagely diesel fuel had the highest share within the total energy inputs, followed by chemical fertilizer in rice production in both TS and MS.

There are a lot of parametric and non-parametric approaches to estimate the efficiency of agricultural production. One of them is the Data Envelopment Analysis approach (DEA); this method is a type of linear programming model that measures a group of decision-making units' relative efficiency. In the traditional data envelopment analysis (DEA) approach for a set of n Decision Making Units (DMUs), a standard DEA model is solved n times, one for each DMU. There are several studies on the application of data envelopment analysis in agricultural productions. Mousavi-Avval et al. (2011) used the DEA technique to evaluate the energy utilization pattern for the manufacture of canola in Iran's Golestan province. The results revealed that all energy used was equal to 17,786 MJ/ha[1]; about 15% of farms were found to be technically efficient. Banaeian et al. (2010) used the method of data analyzing envelope for walnut producers in Iran's Hamadan province to help distinguish efficient and inefficient farmers. The results revealed that 13 walnut producers produced efficiently, while 24 were inefficient. They also calculated the energy saving index (7745 MJ/ha^{-1}) and found that the largest quota of this index appertains to fertilizers (69% nitrogen).

In most previous studies, input and output data are considered to be certain and without deviation. In real problems, this is generally the case because many of the data inputs and outputs are inaccurate. In other words, with a small change in input and output values, the estimates of efficiencies will be completely changed, and their unit rankings will change too (Mardani Najafabadi and Salarpour, 2015). The existence of uncertain data for the agricultural sector is inevitable due to the sampling errors or the use of measures of central tendency. Therefore, the use of techniques that are capable of controlling changes due to uncertain data is extremely necessary.

In recent years, vague and inaccurate data flush theory has been proposed (Egilmez et al., 2016). DEA has been merged with fluid measurement to recognize both optimistic and pessimistic solutions. Fuzzy modeling and DEA have been used by Houshyar et al. (2012) to assess corn cultivation productivity and sustainability in relation to energy consumption in the province of Fars in the South West of Iran. However, some information about insecurity and coefficient distribution is ignored in their methods. Interval DEA (IDEA) is another approach proposed by Cooper et al. (1999) to address uncertainty.

Designing a robust system for parameters (data) should be in way to address the uncertainty (without the greater complexity of the original problem). To be clearer, the system stays practical and works for a variety of values that can be taken up by uncertain parameters in an almost optimal way. In this study, the authors use a robust model of data evolvement analysis (RDEA) to address uncertain situations (Bertsimas and Sim, 2004). In order to address the uncertainties in the analysis, RDEA was implemented. Unlike stochastic and fluid DEA, this method does not conclude that uncertain parameters with known distributions are random variables, the relative efficacy of RDEA DMUs does not have a lower or higher limit than the range approach to complicate the DMU ranking. This model has been used in the study of Mardani Najafabadi and Taki (2020) who have optimized energy consumption for cucumber greenhouses in Golshan city located in central Iran. The highest amount of energy savings in case of following the recommendations of this study was for electricity inputs and agricultural machinery.

Since energy efficiency is very important for the economy, and considering the importance of efficient energy consumption in agricultural crops especially rice as one of the highest energy consumers in the agricultural sector of Golestan province, there was no study on improving energy efficiency in this province. In addition, the application of the RDEA model will overcome the uncertainty in vague data as well as multiple options for deciding on different levels of conservatism for decision makers (Mardani and Salarpour, 2015).

This paper aimed to identify the energy efficiency indices for rice production using the RDEA model in Golestan province, Iran. In addition to these, two aims exist that one of them was to calculate energy efficiency, specific energy, and other energy indicators used in this crop, and the other was to achieve optimal production due to energy savings and thus the economic savings. It should be noted that all these calculations and estimates to achieve the main goals (previously mentioned) of Iranian acts to improve energy consumption in the agricultural sector.

3. Methodology

Using a face-to-face interview and filling out the questionnaire, in this study, the required information and data were collected from 286 rice fields in June 2015. The collected data was related to the production period of 2014. The simple random sampling method was used to determine the number required of samples. The sample size criteria were calculated using a 5% deviation from the average population and 95% confidence. So, the sample size was regarded as 86, and these 286 farms were selected on a random basis.

The energy demand in agriculture can be divided into direct and indirect energy groups. In another classification, it can be divided into two groups of renewable and non-renewable energy resources. Direct energy refers to an inclusive form of energy applied directly to the farm, such as human labor, electricity, and gasoline. On the other hand, indirect energy is not consumed directly, including manure, chemicals, spawn, and agricultural machinery. Renewable energy includes human labor and seed, and non-renewable energy consists of pesticides, chemicals, and manure (Mousavi-Avval et al., 2011).

The questionnaire included questions asking about inputs such as seed, chemicals and manure fertilizers, human power, agricultural machinery (tractor, sprayer, and thresher), and other information about outputs such as paddy yield and chaff yield. In order to estimate the amount of energy by the agronomic method, the yield was defined in MJ/ha^{-1}, and the value of energy coefficients used are reported in Table 1. According to Table 1, the amount of energy equivalency of human labor is 1.96; machinery, 120; and diesel-fuel, 56.31 (MJ/ha^{-1}). There is similar energy equality for other inputs. The notable point about this table is that the energy equivalents are different in the studies for the same inputs. For example, in a research by Ozkan et al. (2004), the energy equivalent for chemical fertilizer (nitrogen) is 60.6 (MJ kg^{-1}), while this element in the study by Esengun et al. (2007) is 66.14 and in the study by Pishgar-Komleh et al. (2011) is estimated to be 78.1 (MJ kg^{-1}). These differences in the calculation of the equivalent of energy are due to different measurement conditions. Therefore, one of the sources of error in DEA can be the energy equivalent employment. Using updated models of data envelopment analysis, such as the RDEA model, overcomes the inaccuracy in the ranking of decision-making units.

The energy equivalent for all inputs and outputs per unit (MJ/ha^{-1}), grain yield (kg/ha^{-1}) for rice production, and the values of energy use efficiency, energy productivity, specific energy, and water productivity are given in Table 1, and calculations are shown in Eqs 1–5 (Khan et al., 2010):

$$Energy\ \ use\ efficiency = \frac{Total\ energy\ output(MJ\ ha^{-1})}{Total\ energy\ input(MJ\ ha^{-1})} \tag{1}$$

$$Energy\ produvtivity = \frac{Grain\ yield(kg\ ha^{-1})}{Energy\ input(MJ\ ha^{-1})} \tag{2}$$

$$Specific\ energy = \frac{Energy\ input(MJ\ ha^{-1})}{Grain\ yield(kg\ ha^{-1})} \tag{3}$$

$$Net\ energy = Total\ energy\ output\left(MJ\ ha^{-1}\right) - Total\ energy\ input\left(MJ\ ha^{-1}\right) \tag{4}$$

The ratio of output-input energy is one indicator that showed the energy efficiency of agriculture. Furthermore, this indicator has no unit, and a higher ratio suggests progress in energy efficiency. In addition, energy productivity is shown by the ratio of the amount of product obtained to the input energy used in the production period (Unakitan et al., 2010). Water productivity is an indicator that showed the proportion of the energy output to the water used in the production period. Data analysis was carried out in this research using Microsoft Excel and the GAMS statistical analysis software.

Table 1
Energy equivalent of inputs and output in rice production.

Particulars	Unit	Energy equivalent (MJ unit^{-1})	Reference
Input			
1. Human labor	h	1.96	Taki and Yildizhan, 2018
2. Machinery	h	62.7	Taki et al. (2018c)
3. Diesel	l	56.31	Yildizhan and Taki (2019)
4. Fertilizer	kg	–	–
Nitrogen (N)		60.6	Abdi et al. (2012)
Phosphate(p2o5)		11.1	Abdi et al. (2012)
Potassium (K2O)		6.7	Abdi et al. (2012)
Manure		0.3	Abdi et al. (2012)
5. Chemicals	kg	–	Abdi et al. (2012)
Insecticides		199	Elhami et al. (2021)
Fungicides		92	Elhami et al. (2021)
Herbicides		238	Elhami et al. (2021)
6. Water for irrigation	m^3	0.63	Elhami et al. (2021)
7. Seeds	kg	14.57	Taki et al. (2018c)
Output	–	–	–
8. Grain yield	kg	17	Ranjbar et al. (2013)
9. Straw	kg	12.5	Ranjbar et al. (2013)

3.1. Application of DEA approach with accurate data

One of the most powerful nonparametric methods to measure the efficiency of a collection of homogenous Decision Making Units (DMUs) is the DEA technique. When using DEA to calculate efficiency, certain restrictions, such as the sensitivity of DEA to specific data, need to be taken into account (Sabouhi and Mardani, 2017). In this section, DEA method, which includes two models, CCR (or CRS) and BCC (or VRS) was applied for the assessment of the technical efficiency. Based on the Cooper method, to assess the efficiency score of a unit under review, we used linear programming (LP) as follows (Cooper et al., 2006):

$$\max: \quad \theta = \sum_{r=1}^{m} u_r y_{ro} \tag{5}$$

$$\begin{aligned} s.t: \quad & \sum_{i=1}^{n} v_i x_{io} = 1 \\ & \sum_{r=1}^{m} u_r y_{rj} - \sum_{i=1}^{n} v_i x_{ij} \le 0 \qquad j = 1, \dots, s \\ & u_r \ge \varepsilon \ \ , \ v_i \ge \varepsilon \end{aligned} \tag{6}$$

where m is the number of inputs $(i = 1, \dots, n)$, n is the number of outputs

$(r = 1,...,m)$, s is the number of DMU_S $(j = 1, 2, ..., S)$, $\theta_j (j = 1, 2, ..., S)$ is the technical efficiency score related to DMU_j, v is the input weight, u is the output weight, x is the input, and y is the output. In return for the scale (CRS) model, it is assumed that a certain rise in inputs can lead to an equitable increase in output, and the slope of the production function in this model is continuous (Charnes et al., 1978). Technical efficiency is calculated by adding variable w as a less strict variable into return to scale under a relative estimate of efficiency (Mardani Najafabadi et al., 2020a).

The technical efficiency (under CRS approach) can be decomposed into pure technical efficiency (or PTE) and scale efficiency (or SE) as follows (Mardani Najafabadi et al., 2020b):

$$SE = \frac{TE_{CCR}}{PTE_{BCC}} \tag{7}$$

The optimal values of input j of DMU_j (x^*_{ij}) can be calculated as follows (Tone et al., 2011):

$$x^*_{ij} = mv_j x_{ij} \tag{8}$$

where mv_o is the marginal value of the second constraint ($\sum_{r=1}^{m} u_r y_{rj} - \sum_{i=1}^{n} v_i x_{ij} \leq 0$) of Eq. (5). The subtraction of the actual value (x_{ij}) and the optimal value (x^*_{ij}) is the total reduction quantity (target) that can be lessened without reducing the output levels. The above subtraction is called the energy-saving target (EST) for energy input. The formula is as follows:

$$EST_{ij} = x_{ij} - x^*_{ij} \tag{9}$$

Based on the optimal values of energy obtained from DEA, we can calculate the ESTR. The formula is as below (Hu and Kao, 2007):

$$ESTR_i(\%) = \frac{\sum_j EST_{ij}}{\sum_j x_{ij}} \times 100 \tag{10}$$

3.2. Data uncertainty and RDEA model

In each constraint, the number of uncertain parameters is the upper limit of parameter Γ; thus, the ranges of uncertainty level parameters Γ^y_1 Γ^x_2, and Γ^{xy}_3 are $[0, J^y_1]$, $[0, J^x_2]$, and $[0, J^{xy}_3]$,respectively. Furthermore, $\Gamma^{xy}_3 \in [0, |J^y_1| + |J^x_2|]$ because Γ^y_1 and Γ^x_2 show the conservatism level of DMU inputs and outputs. The robust DEA model formulated by Shokouhi et al. (2010) applied the robust optimization method proposed by Bertsimas and Sim (2004) and is defined as follows:

$$\text{Max} \quad \theta_o = \sum_{r=1}^{s} u_r y^U_{ro} - z_o \Gamma^y_1 - \sum_{r=1}^{s} p_{ro} \tag{11}$$

st:

$$\sum_{i=1}^{m} v_i x^L_{io} + z_o \Gamma^x_1 + \sum_{i=1}^{m} q_{io} = 1$$
$$\sum_{r=1}^{s} u_r y^L_{rj} - \sum_{i=1}^{m} v_i x^U_{ij} + z_j \Gamma^{xy}_3 + \sum_{r=1}^{s} p_{rj} + \sum_{i=1}^{m} q_{ij} \leq 0 \quad \forall j \tag{12}$$

$$\begin{aligned} & z_j + p_{rj} \geq u_r \left(y^U_{rj} - y^L_{rj} \right) && \forall r, j \\ & z_j + q_{ij} \geq v_i \left(x^U_{ij} - x^L_{ij} \right) && \forall i, j \\ & \Gamma^x_1 + \Gamma^y_1 = \Gamma^{xy}_3, \\ & \theta_o \leq 1, \\ & \Gamma^y_1 \leq s, \\ & \Gamma^x_1 \leq m, \\ & u_r, v_i, z_j, p_{rj}, q_{ij} \geq 0, && \forall i, j, r \end{aligned} \tag{13}$$

where z_j,p_{rj}, and q_{ij} are additional parameters for every robust problem limit. Note that, while $\Gamma^{xy}_3 = 0$, the highest value belongs to z_j, and zero value belongs to p_{rj},q_{ij}. It is acceptable that parameters z_j, p_{rj}, *and* q_{ij} have no effect on Eq. (11). When $\Gamma^{xy}_3 \in [0, |J^{xy}_3|]$, is the level of safety against limitations and the level of conservatism (Mardani Najafabadi and Abdeshahi, 2019).

4. Results and discussion

The amounts of inputs used, the output produced, as well as energy equivalents of inputs and outputs in rice production, are illustrated in Table 2.

In this table, the energy value (MJ ha^{-1}) of different input variables and outputs used in the production of rice by measuring the energy equivalent of any resources (total energy equivalent) are illustrated.

For example, the total equivalent of human labor energy (consumption) is measured by multiplying the amount of energy coefficient of human labor (1.96 MJ h^{-1} from Table 1) by the use of manpower (681.4 h ha^{-1}). So, the outcome is the amount of energy used by human labor in rice production (1335.5 MJ ha^{-1}). Other energy consumption can also be estimated. All different energy input variables and output values of 34,423 and 120,088 MJ ha^{-1} (sum of the two outputs) were calculated. Data analysis showed that the highest share of all fertilizers is the energy used by nitrogen fertilizers (including nitrogen, phosphorus, potassium, and manure), which was similar to study reports by Yuan and Peng (2017) in central China and in Kazemi et al. (2015) northern provinces of Iran. The amount of energy embedded in fertilizers contributed to 36.9% of the total energy use. After fertilizers, total energy uses of diesel and water for irrigation play an important role with the share of 21% and 20.5% of the total energy use, respectively. These results are in line with some studies in different regions of Iran (Kazemi et al., 2015) and some parts of Asia (Khan et al., 2010). The fuel energy consumption was the highest among other inputs in rice production in Iran, due to the low fuel price resulting from government subsidies (Pishgar-Komleh et al., 2011) and old machinery and equipment (Hormozi et al., 2012). Applying more energy efficiency equipment like new machinery and irrigation pumps decreases the amount of energy usage. The yields of rice grain and straw are the basis for calculating the output of energy. Therefore, the management observed high energy output that generated high yields. The obtained results showed that Golestan's energy output is higher than many previously reported values in other

Table 2
Amounts of inputs, output, and energy inputs and output for rice.

	Quantity per unite (ha)	Total energy equivalent (MJ ha^{-1})	Percentage of energy (%)
Input			
1. Human labor (h)	681.4	1335.5	3.9
2. Machinery (h)	43	2694.6	7.8
3. Diesel (l)	128.6	7241.7	21.0
4. Fertilizer (kg)	–	–	–
Nitrogen (N)	170.1	10,309	29.9
Phosphorus (P_2O_5)	144.2	1600.5	4.6
Potassium (K_2O)	90.7	607.7	1.8
Manure	683.7	205.1	0.6
5. Chemicals (kg)	–	–	–
Insecticides	3.7	735.8	2.1
Fungicides	1.5	142.3	0.4
Herbicides	3.3	786	2.3
6.Water for irrigation (m^3)	11,186	7047.18	20.5
7. Seeds(kg)	117.9	1717.9	5.0
Total energy input	–	34,423.28	100.0
Output			
Grain yield)Kg(	5000	72,850	60.7
Straw)Kg(	3779.1	47,238.4	39.3
Total energy output	–	120,088.4	–

Table 3
Some energy indices in rice production in Golestan province, Iran.

	Unit	Quantity
Energy use efficiency	–	3.58
Energy productivity	Kg MJ^{-1}	0.14
Specific energy	MJ kg^{-1}	6.88
Net energy	MJ kg^{-1}	85,665.12
Direct energy [a]	MJ ha^{-1}	15,624.38 (45%)
Indirect energy [b]	MJ ha^{-1}	18,798.9(55%)
Renewable energy [c]	MJ ha^{-1}	14,239.4 (41%)
Non-renewable energy [d]	MJ ha^{-1}	20,183.88(59%)
Total energy input	MJ ha^{-1}	34,423.28

[a] Indicates human labor, diesel, and water.
[b] Indicates seeds, fertilizers, chemicals, and machinery.
[c] Indicates human labor, seeds, and water.
[d] Indicates diesel, fertilizers, chemicals, and machinery.

Iranian regions (Kazemi et al., 2015).

Table 3 lists rice production energy indices and types of energy inputs. The energy consumption efficiency in rice production was reported to be 3.58; this shows that the total amount of output energy in rice production is almost three times higher than the total amount of input energy. So, energy consumption efficiency estimate was higher than many researcher's reports (Mardani Najafabadi et al., 2020b). and lower than some other (Yuan and Peng, 2017). Energy productivity and specific energy of rice were 0.14 $kgMJ^{-1}$ and 6.88 MJ $(m3)^{-1}$, respectively. However, in a similar study in Australia, energy productivity was 1.48 kg MJ^{-1} (Khan et al., 2010), and in Iran, it was 0.064 (Alipour et al., 2012).

The best way to increase energy efficiency and reduce specific energy for rice production can be done by increasing production and reducing input energy consumption per hectare. For this purpose, determining the optimal amount of energy use by increasing the efficiency of similar units is a suitable and economical solution. Of course, it should be noted that this solution will be successful if the amount of production per hectare of rice is constant or increases.

In Table 3 shows energy types, including direct and indirect, which account for 45% and 55%. Renewable and non-renewable energy shares represent 41% and 59% of the total amount of energy input, respectively. The rice production of the study area is mainly affected by the type of non-renewable energies. In other words, it is highly dependent on non-renewable energies such as fossil fuels because of high non-renewable energy ratio.

4.1. Estimation of efficiency

The results of the use of input-oriented CRS and VRS RDEA models for conservatism 7 ($\Gamma = 7$) are presented in Table 4. According to the results, about 50% of farmers (43 farmers) were technically and purely technically efficient. This means that at this level, half of the farmers are inefficient. It is also clear that 2 and 26 rice producers had technical efficiency under 0.7 in the VRS and CRS approach, respectively. The presence of this number of farms in inefficient units indicates the inappropriate use of agricultural inputs to produce rice crops in the study area.

Table 4
Efficiency score distribution for CRS and VRS models ($\Gamma = 7$).

	Number of farmers falling in ranges		
	Range	The CRS case	The VRS case
Efficient	Equal to 1	43	43
Inefficient	0.9 to <1	0	2
	0.8 to <0.9	6	19
	0.7 to <0.8	11	20
	0.6 to <0.7	15	2
	0.5 to <0.6	8	0
	0.4 to<0.5	1	0
	0.3 to<0.4	2	0

Statistics for the three estimated efficiency measures are summarized in Table 5 for level $\Gamma = 7$. The results showed that, on average, rice producers had a technical efficiency equal to 0.70, pure technical efficiency equal to 0.73, and scale efficiency equal to 0.76. This outlines growing scale returns. In addition, the amount of technical efficiency range varied between 0.35 and 1, and the standard deviation (SD) was 0.18. The wide variety in agricultural techniques shows that farmers were either not well aware of or properly aware of acceptable production techniques. The important point in this table is that the average efficiency score of the scale is higher than the technical one, and this shows that the skills of efficient farmers in cultivating this crop and optimal use in energy consumption are high. This can be used to bring farms that are inefficient closer to efficiency by using the experiences of these farmers.

Fig. 1 provides a sensitivity analysis of Γ for efficiency score and shows how it declines as the Gama parameter increases. If all Gammas are equal to 0, robust and original DEA models are the same according to the method. Reducing the average scale efficiency from 0.92 to 0.76 (26% decrease) indicates that increasing the level of conservatism leads to a gap between efficient and inefficient units. Application of robust DEA in other studies also confirms this result (Mardani and Salarpour (2015)).

4.2. Definition of realistic levels of input for inefficient farmers

Data used to set realistic levels of input (optimal energy consumption) based on the results of the VRS model for $\Gamma = 7$ (highest level of protection) and $\Gamma = 0$ (traditional DEA) are presented in Table 6.

Percentage change of ESTR value will be from 0 to 100%, and a greater percentage indicates the inefficient energy consumption of inputs. As an example, the ESTR for water irrigation was at least 5.59% for level $\Gamma = 7$, which revealed that farmers in the region mainly used water efficiently. Moreover, the calculation of ESTR showed that fertilizers are the most important items for managing energy consumption in this region (ESTR = 27.45%). Pishgar-Komleh et al. (2011) reported that the main reason for the use of fertilizers is the weakness management of farmers (farmer's poor knowledge) and governors (subsidies price). In addition to these two reasons, in this area, poor soil quality has also led to unsustainable use of fertilizers. The table also shows how the optimum energy consumption, energy saving, and ESTR decreased as the solution's conservatism in all inputs increased. We suggest that the energy saving target ratio percentage should be applied to the sources of optimal consumption for inefficient farmers. To do this, using the RDEA model results seems to be more suitable due to the uncertainty in energy data.

Fig. 2 shows the distribution of total energy saving and saving target ratio (ESTR) for rice production at five levels of conservatism in the VRS model. It is evident that, with an increased level of conservatism, the total energy saving and ESTR could be reduced. No study has used the robust DEA model in the field of energy efficiency to study the Gamma sensitivity analysis of saving energy and ESTR. However, many studies have used the robust optimization model in other fields. For example, Mardani Najafabadi and Taki (2020) in their study only analyzed the sensitivity in uncertainty conditions to estimate the efficiency score in the RDEA model.

The consentient protection for each problem has a different effect

Table 5
Average efficiency of rice farmers for $\Gamma = 7$

	Mean	SD	Min	Max
Technical efficiency	0.70	0.18	0.35	1
Pure technical efficiency	0.73	0.11	0.67	1
Scale efficiency	0.76	0.12	0.41	1

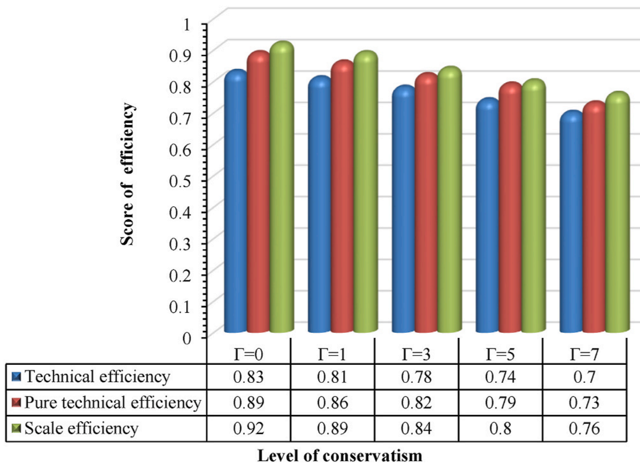


Fig. 1. Efficiency score of rice production in Golestan province based on the results of VRS model.

and in our study (energy efficiency) leads to a decrease in the score of efficiency and then reduces the amount of energy saving and ESTR.

Now that all the results related to the calculations and the RDEA model have been determined, it is necessary to examine the coordination of the results with the existing acts in Iran to improve energy consumption in the agricultural sector. Table 7 summarizes the main goals of these acts, which were mentioned in the introduction section, along with examining the ability of the results to achieve these goals. According to Table 7, modifying consumption patterns and improving energy productivity (Goal 1) will be fully achieved; by determining efficient farms, the consumption pattern of these farms can be set as a pattern for inefficient farms, and this has reduced the energy consumption of inputs, which in turn will increase the productivity of inefficient farms. Of course, it is necessary to mention that it is not possible to generalize this result to other regions of Iran. As noted in the review of liteature, the inputs that have caused the inefficiency of rice producers in other parts of Iran are different.

Goal 2, which is related to setting the standard for optimal energy consumption, can also be achieved according to the results of Table 6 and Fig. 2. Of course, it should be noted that in this goal as well as goal 1, it is not possible to generalize the results to other regions of Iran.

Regarding goal 3, it should be said that this goal is almost achieved. In this study, the inputs that have led to inefficiency of some rice producers in energy consumption can be determined. However, the study of factors affecting the non-optimal use of energy resources in these farms needs another study. Determining these factors from an economic, social and cultural point of view, although very important, is not within the scope of this study.

Determining alternatives to obsolete equipment and machinery or reviewing technology upgrades (Goal 4) is not generally the subject of this study. Of course, determining the share of agricultural machinery in the amount of energy reserves for rice producers helps a lot to inform decision makers about the distribution of financial resources to replace or upgrade technology. Finally, it can be said that the present study was conducted according to the needs of Golestan province and from the point of view of macro policies, it has a suitable coverage for Iranian acts.

5. Conclusions

Optimizing energy consumption in the ecosystem of agricultural

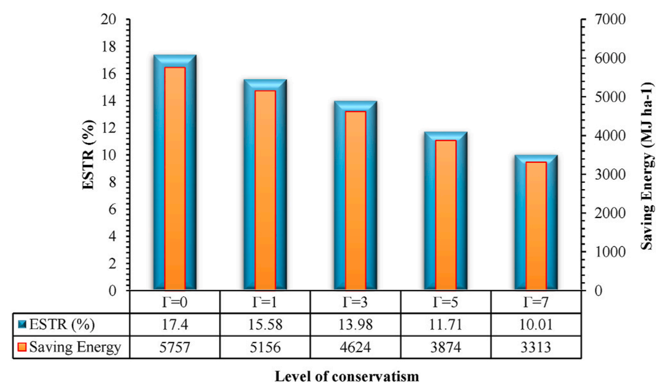


Fig. 2. ESTR (%) based on VRS model for rice production inputs at different levels of conservatism.

Table 7
The main goals of the acts on optimizing the pattern of energy consumption in the agricultural sector of Iran.

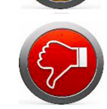
The main purposes of the acts	The Acts	Final result
1.Improving consumption patterns and energy productivity in the agricultural sector for each crop and region	*Articles of Association of the Renewable Energy and Energy Efficiency Organization (Note 1 and 2 - Article 1)	
2.Determining the standard of optimal energy consumption for each unit of cultivated area of crop in each region	*Act on the Sixth Five-Year Plan for Economic, Social and Cultural Development of Iran (Article 44 of Section 10) *National Document of Iran's Energy Strategy	
3.Determining the factors affecting the non-optimal energy consumption for each crop and region	* Act on Energy Consumption Pattern Reform (Chapter 7-Article 28)	
4.Determining alternatives or upgrading technology for energy-intensive inputs in the agricultural sector	*Act on Modification of Energy Consumption Pattern (Chapter 7-Articles 29 and 30)	

Table 6
Optimum energy requirement and saving for level conservation $\Gamma = 7$ and 0.

		$\Gamma = 0$ (DEA)			$\Gamma = 7$ (RDEA)		
	Present use (MJ ha^{-1})	Optimal energy requirement (MJ ha^{-1})	Saving Energy (MJ ha^{-1})	ESTR (%)	Optimal energy requirement (MJ ha^{-1})	Saving Energy (MJ ha^{-1})	ESTR (%)
Human labor	1335.5	1122.1	213.4	15.98	1269.7	65.8	4.93
Machinery	2694.6	2233.9	460.7	17.1	2489	205.6	7.63
Diesel	7241.7	6587.2	654.5	9.04	7056.8	184.9	2.55
Total fertilizer	12,722	8655.5	4066.5	31.96	9229.9	3492.1	27.45
Total chemicals	1664.1	1341.11	322.99	19.41	1544.2	119.9	7.21
Water for irrigation	7047.18	6001.4	1045.78	14.84	6653.5	393.68	5.59
Seeds	1717.9	1389	328.9	19.15	1530.9	187	10.89
Total energy input	34,423.28	27,330.21	5757.27	17.4	29,774	3313.48	10.01

systems can help reduce the cost of agricultural operations, improve air quality, reduce greenhouse gas emissions and sustainable development. In this study, the energy efficiency of rice farmers in Golestan province, Iran was calculated to determine the optimal energy consumption of inputs in this product. In general, the results showed that half of the producers were efficient and the efficiency of the scale was higher than the technical efficiency, which indicates the good performance of efficient farmers in rice production. Also, the amount of energy saving was higher than other inputs in case of optimal use of production inputs in inefficient units for fertilizers and chemicals. A review of Iranian government acts to improve the pattern of energy consumption in the agricultural sector showed that the results of this study have good coverage to achieve the main goals of these acts. Training courses for farmers to reduce chemical fertilizers consumption, as well as a reduction in subsidies for chemical fertilizers, can help reduce the consumption of this input, which will reduce the waste of energy. Conducting soil tests to know the nutritional needs of plants as well as testing the water used in rice cultivation can be a very effective guide for inefficient farmers in using chemical fertilizer inputs. Also, biological control can be used to reduce the consumption of chemicals. For example, biological control of striped rice stem borer (Chilo suppressalis), which is one of the most important pests in the study area, is carried out by Trichogramma. Of course, it should be noted that to do this, integrated pest management training to farmers is important.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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