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Reduction of greenhouse gas emissions of eggplant production by energy optimization using DEA approach

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ABSTRACT

The main objective of this study was the determination of optimum energy requirement and potential of greenhouse gas (GHG) reduction of eggplant production by non-parametric method of data envelopment analysis (DEA) in Guilan province, Iran. The BCC and CCR models of DEA were applied to energy optimization. The results showed the 29, 39 and 30 units had the score equal one in technical, pure technical and scale efficiency, respectively. Also, the average of technical, pure technical and scale efficiency was calculated as 0.771, 0.956 and 0.806, respectively. The total saving energy was about 2830 MJ ha^{-1} and diesel fuel had the highest share of total energy saving with 48.49%. The energy use efficiency of target units was more than present units about 26%. The GHG emissions analysis indicated that total GHG emissions of present and optimum units were about 515 and 401 $kgCO_{2eq.}$ ha^{-1}, respectively. So, the total potential of GHG emissions reduction was found about 115 $kgCO_{2eq.}$ ha^{-1}. Moreover, the diesel fuel had the highest percentage of GHG emissions reduction by 58.58%; followed by machinery with 17.24% and nitrogen with 15.12%. Generally, it can be said the DEA approach was appropriate methods for energy optimization and reduction of GHG emissions in eggplant production.

Introduction

Energy in agriculture is important in terms of crop production and agro processing for value adding. Human, animal and machinery is extensively used for crop production in agriculture. Energy use depends on mechanization level, the quantity of active agricultural worker and cultivable land. Efficient use and study impacts of these energies on crop production help to achieve increased production and productivity and help the economy, profitability and competitiveness of agricultural sustainability of rural communities (Singh *et al.*, 2002). Eggplant (*Solanum melongena L.*), also known as Aubergine, Brinjal or Guinea squash is one of the nontuberous species of the nightshade family Solanaceae (Kantharajah and Golegaonkar, 2004). One of the most important issues in recent century is the global warming, and greenhouse gas (GHG) emission is the main factor of this happening. There is scientific consensus that global warming will pose one of the major environmental challenges in the future. While the bulk of the so called GHGs originates from fossil fuel consumption (Pathak and Wassmann, 2007). Production, transportation, storage, distribution of the inputs and application with machinery lead to combustion of fossil fuel and use of energy from alternate sources, which also emits greenhouse gases into the atmosphere. Thus, an understanding of the emissions expressed in kilograms of carbon equivalent (kg CE) for different tillage operations, fertilizers and pesticides use, supplemental irrigation practices and harvesting is essential to identifying C-efficient alternatives such as biofuels and renewable energy sources for seedbed preparation, soil fertility management, pest control and other farm operations (Pishgar-Komleh *et al.*, 2012). Data envelopment analysis (DEA) is known as a mathematical procedure that uses a linear programming technique to assess the efficiencies of decision-making units (DMU). A non-parametric piecewise frontier, which owns the optimal efficiency over the datasets, is composed of DMUs and is constructed by DEA for a comparative efficiency measurement.

Those DMUs that are located at the efficiency frontier are efficient DMUs. These DMUs own the best efficiency among all DMUs and have their maximum outputs generated among all DMUs by taking the minimum level of inputs (Lee and Lee, 2009). In recent years, there have been numerous applications of DEA to measure the energy efficiency and GHG emissions reduction in agricultural production systems. Khoshnevisan *et al.* (2013a) applied the DEA technique to analyze the efficiency and CO_2 emissions reduction of input use in cucumber production. In another study by Khoshnevisan *et al.* (2013b), the DEA technique was subjected to the data on energy use and GHG reduction for wheat production from 260 farmers in Isfahan province, Iran. Nabavi-Pelesaraei *et al.* (2014) investigated the optimization of energy inputs for orange production and comparison between efficient and inefficient producers from the GHG emissions point of view using DEA approach.

Based on the literature, there has been no study on application of DEA for assessing the impact of improving energy use efficiency on GHG emission. Accordingly, the objectives of this study were: (a) to determine the efficiencies of eggplant farmers; (b) to identify target energy requirement and wasteful uses of energy and (c) to assess the effect of energy optimization on GHG emissions.

Materials and methods

Sampling design

Guilan province is located in the North of Iran, within 36° 34′ and 38° 27′ north latitude and 48° 53′ and 50° 34′ east longitude.

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This province is the main center of eggplant productions in the country (Anon, 2012). The data used in the study were collected from 60 eggplant farms in 6 villages of Langroud city using a face-to-face questionnaire in March 2013. The collected data belonged to the production period of 2012–2013. The simple random sampling method was used to determine the survey volume, as described by Mobtaker *et al.* (2010).

Energy equivalents of inputs and output

The data included the quantity of various energy inputs used per hectare of eggplant production, including: human labor, machinery, diesel fuel, seed, biocides and chemical fertilizers and the eggplant yield as single output. The energy coefficient was applied for converting inputs to energy in this study (Table 1). Also, output energy was obtained from multiplying eggplant yield with corresponding coefficient, which is shown in Table 1. The results revealed that total average energy and eggplant yield were calculated about 13911 MJ ha^{-1} and 5024 kg ha^{-1}. As can be seen in Table 1, the diesel fuel and nitrogen were the highest energy consumer with 6849.41 and 4631.98 MJ ha^{-1}, respectively.

Data envelopment analysis (DEA)

Data envelopment analysis (DEA) is a method to estimate non-parametric efficiency frontiers in multi-product and multi-input systems. DEA involves the use of linear programming to build a non-parametric surface over the data; thus, efficiency measures are calculated relative to this surface or frontier. In this study, input-oriented DEA seems more appropriate, given that it is more reasonable to argue that in the agricultural sector a farmer has more control over inputs rather than output levels. DEA allow for the measurement of relative efficiency for a group of DMUs that use various inputs to produce outputs. The concepts used in the parametric and DEA approaches are demonstrated in Fig. 1 where the case of seven DMUs with single inputs and single outputs is considered (Lee and Lee, 2009). The input and output are shown on the x and y axes, respectively. The filled rhombuses represent different DMUs in the data set. In Fig. 1, P1, P2, P3 and P4 are the boundary points. The solid line joining these points forms the envelope for the data set. The DMUs lying on the boundary and represented by points P1, P2, P3 and P4 are considered as efficient DMUs, and the efficiency of other DMUS, P5, P6 and P7 are calculated by comparing with these efficient DMUs.

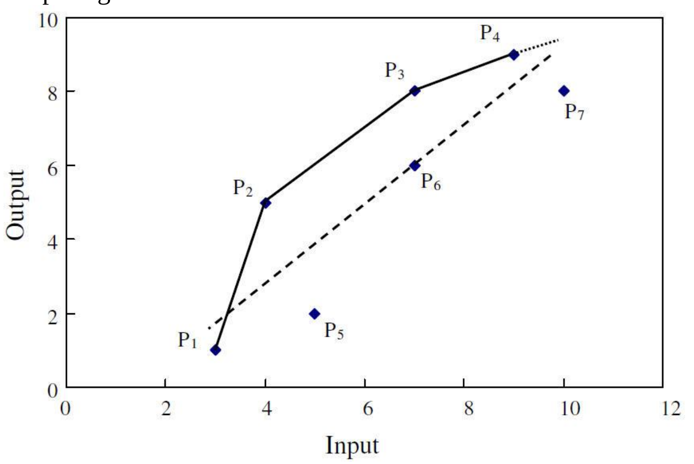

Fig. 1. Comparison of DEA and regression analysis (Lee and Lee, 2009)

Technical efficiency

Technical efficiency (TE) can be calculated by the ratio of the sum of weighted outputs to the sum of weighted inputs (Pahlavan *et al.*, 2011):

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

Where, u_r, is the weight given to output n; y_r, is the amount of output n; v_s, is the weight given to input n; x_s, is the amount of input n; r, is number of outputs ($r = 1, 2, \ldots, n$); s, is the number of inputs ($s = 1, 2, .., m$) and j, represents *jth* of DMUs ($j = 1, 2, \ldots, k$). Eq. (1) is a fraction problem, so it can be translated into a linear programming problem which is introduced by Charnes *et al.* (1978):

$$\text{Maximize} \quad \theta = \sum_{r=1}^{n} u_r y_{rj}$$

$$\text{Subjected to} \quad \sum_{r=1}^{n} u_r y_{rj} - \sum_{s=1}^{m} v_s x_{sj} \le 0 \qquad (2)$$

$$\sum_{s=1}^{m} v_s x_{sj} = 1$$

$$u_r \ge 0, \; v_s \ge 0, \quad \text{and (i and j= 1, 2, 3, ..., k)}$$

Where θ is the technical efficiency, Model (2) is known as the input oriented CCR DEA model assumes constant returns to scale (CRS) (Avkiran, 2001).

Pure technical efficiency

Banker, Charnes and Cooper introduced a model in DEA, which was called BCC model to draw out the technical efficiency of DMUs (Banker *et al.*, 1984). With respect to technical efficiency (in CCR model), technical efficiency of BCC model, which is called Pure Technical Efficiency, could separate both technical and scale efficiencies. It can be expressed by Dual Linear Program (DLP) as:

$$\text{Maximize} \quad z = uy_i - u_i$$
$$\text{Subjected to} \quad vx_i = 1 \qquad (3)$$
$$-vX + uY - u_o e \le 0$$
$$v \ge 0,\; u \ge 0 \;\text{ and }\; u_o \;\text{ free in sing}$$

Where z and u_0 are scalar and free to sign; u and v are output and input weight matrixes, and Y and X are the corresponding output and input matrixes, respectively. The letters x_i and y_i refer to the inputs and output of ith DMU.

Scale efficiency

Scale efficiency shows the effect of DMU size on efficiency of the system. Simply, it indicates that some part of inefficiency refers to the inappropriate size of DMU, and if DMU moved toward the best size the overall efficiency (technical) can be improved at the same level of technologies (inputs) (Nassiri and Singh, 2009). If a DMU is fully efficient in both the technical and pure technical efficiency scores, it is operating at the most productive scale size. If a DMU has the full pure technical efficiency score, but a low technical efficiency score, then it is locally efficient but not globally efficient due to its scale size. Thus, it is reasonable to characterize the scale efficiency of a DMU by the ratio of the two scores

The relationship between the scale efficiency, technical efficiency and pure technical efficiency can be expressed as follows (Mousavi-Avval *et al.*, 2012):

$$\text{Scale efficiency} = \frac{\text{Technical efficiency}}{\text{Pure technical efficiency}} \qquad (4)$$

Greenhouse gas (GHG) emissions

The CO_2 emission coefficients that are shown in Table 2 were used to calculate the amounts of the GHG emission from inputs in eggplant production per hectare before and after optimization of energy consumption in eggplant production. The application rate of machinery, diesel fuel, chemical fertilizers and biocides per hectare were multiplied by their corresponding emission coefficients which were taken from Table 2. In the last section of this paper, the reduction of GHG emissions by the DEA was determined for the studied area. Also, the percentage of GHG reduction was obtained for each input.

Basic information on energy inputs in eggplant production were entered into Excel 2013 spreadsheets, and Efficiency Measurement System (EMS) 1.3 software programs.

Results and Discussion

Efficiency estimation of farmers

In this study, we used CCR and BCC models to evaluate technical, pure technical and scale efficiencies of eggplant producers, respectively. Fig. 2 displays the results of the CCR and BCC models. Based on CCR results, this study shows that 29 farms were relatively efficient and the remaining 31 were inefficient, i.e. their efficiency score was below 1. While based on BCC model, 39 farms were efficient and the remaining were inefficient. As can be seen in Fig. 2, the rate of scale efficiency was 1 for 30 units. Obviously, the efficiency score was equal to one unit, but the its score was less than 1.

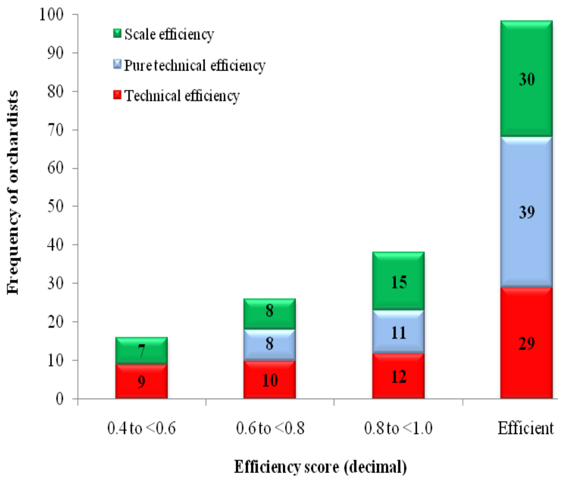

Fig. 2. Efficiency score distribution of eggplant producers.

The rate of three indices of DEA is given in Table 3 with standard deviation, minimum and maximum values. It should be noted, the value of these indexes was based on the results of the models (2) and (3) and Eq. (4). The results illustrated average of technical, pure and scale efficiency of eggplant farmers were 0.771 (with the standard deviation of 0.13), 0.956 (with the standard deviation of 0.12) and 0.806 (with the standard deviation of 0.13) respectively.

Mousavi-Avval *et al.* (2011) applied the DEA technique to determine the efficiencies of farmers in soybean production in Iran. They reported that the technical, pure technical and scale efficiency scores were 0.85, 0.92 and 0.93, respectively. In another study, the efficiency of alfalfa production was analyzed and these efficiency indices were reported 0.84, 0.97 and 0.89, respectively (Mobtaker *et al.*, 2012).

Optimum energy requirement and saving energy

Table 4 shows the optimum energy consumption and saving energy of various farm inputs based on BCC model. Accordingly, the total optimum energy required of eggplant production was found about 11081 MJ ha^{-1}. In the second column of Table 4, the rate of saving energy is given. Saving energy was obtained from the difference between optimum condition and present farms for each input and total energy consumption. The results revealed that total energy saving was 2829.80 MJ ha^{-1}, meaning the use of DEA approach can reduce the total energy input about 2830 MJ ha^{-1}; While the eggplant yield remained constant. As can be seen in the last column of Table 4, the diesel fuel had the highest share of total energy saving with 48.49%; followed by nitrogen 31.21%. The reason of these results were low cost of energy inputs, lack of maintenance at the right time, indiscriminate use of chemical fertilizers (especially nitrogen), applying inappropriate machinery and electro pump for extracting water to irrigation and wrong think of farmers (the increasing use of chemical inputs can increase the yield) in the studied area. So, it's suggested the energy use pattern of units should be close to optimal units. For this purpose, the selection of standard machinery, timely maintenance of machinery for the reduction of diesel fuel and reduce of chemical fertilizers with using manure instead of nitrogen should be considered for eggplant production in Guilan province of Iran.

Chauhan *et al.* (2006) reported that the contribution of fertilizer and diesel energy inputs from total saving energy in paddy production were 33% and 24%, respectively. Mousavi-Avval *et al.* (2011) reported that the contribution of electricity and seed energy inputs by 78.1% and 0.05% from total energy saving in soybean production were the highest and lowest, respectively.

Improvements of energy indices

The energy indices for present and target units of eggplant production are presented in Table 5. Based on BCC model results, the energy use efficiency, energy productivity and net energy of optimum units were calculated as 11.34, 1.92 kg MJ^{-1} and 114531.13 MJ ha^{-1}, respectively; While these rates of indices for present farms were 9.03, 1.53 kg MJ^{-1} and 111701.33 MJ ha^{-1}, respectively. In other word by applying DEA, the energy use efficiency, energy productivity and net energy were better than about 26%, 25% and 3%, respectively. Moreover, the energy intensiveness as one of important energy-economic indices were less than about 20% in target toward present units. Furthermore, the energy forms, including direct, indirect, renewable and non-renewable energy were calculated for the present and target units and these results are given in Table 5. The results indicated, all energy forms consumption in optimum units was less than present farms and the highest percentage reduction of energy forms were belonged to indirect and non-renewable energy with 22.33% and 21.15%, respectively.

Mohammadi *et al.* (2011) reported the DEA method can be improved the energy use efficiency of kiwifruit production about 14%. Also, their results showed the indirect energy with 16.15% had the highest reduction by DEA approach.

Reduction of Greenhouse gas emission

Based on Table 2 the GHG emissions from eggplant production were computed for present and target units and their quantity are listed in Table 6. The results revealed that total GHG emissions of present and optimum farms were calculated as 515.37 and 400.56 $kgCO_{2eq.}$ ha^{-1}, respectively. In the last column of Table 6, the difference of GHG emissions between the present and target units was calculated as GHG emissions reduction. So, using the DEA approach, the total GHG emissions of eggplant production can be reduced about 115 $kgCO_{2eq.}$ ha^{-1}.

The share of each input for GHG emissions reduction by energy optimization are demonstrated in Fig. 3. The highest share of GHG emissions reduction was belonged to diesel fuel with 58.58%; followed by machinery with 17.24% and nitrogen with 15.12%.

Table 1. Energy coefficients and energy inputs/output in various operations of eggplant production

Inputs (unit)	Energy equivalent (MJ unit^{-1})	Quantity per unit area (ha)	Total energy equivalent (MJ ha^{-1})
A. Inputs			
1. Human labor (h)	1.96 (Mobtaker et al., 2012a)	325.06	637.12
2. Machinery (h)	62.70 (Rafiee et al., 2010)	12.93	810.93
3. Diesel fuel (L)	56.31 (Barber, 2003)	121.64	6849.41
4. Chemical fertilizers (kg)			
(a) Nitrogen	66.14 (Nabavi-Pelesaraei et al., 2013a)	70.03	4631.98
(b) Phosphate (P_2O_5)	12.44 (Unakitan et al., 2010)	29.95	372.58
(c) Potassium (K_2O)	11.15 (Pahlavan et al., 2011)	17.29	192.73
5. Biocides (kg)	120 (Nabavi-Pelesaraei et al., 2013b)	3.43	411.20
6. Seed (kg)	25 (Kitani, 1999)	0.19	4.72
The total energy input (MJ)			13910.67
B. Output			
1. Eggplant (kg)	25 (Kitani, 1999)	5024.48	125612.00

Table 2. Greenhouse gas (GHG) emissions coefficients of agricultural inputs

Input	Unit	GHG Coefficient (kg $CO_{2eq.}$ unit^{-1})	Reference
1. Machinery	MJ	0.071	(Dyer and Desjardins, 2006)
2. Diesel fuel	L	2.76	(Dyer and Desjardins, 2003)
3. Chemical fertilizers	kg		
(a) Nitrogen		1.3	(Nabavi-Pelesaraei et al., 2014)
(b) Phosphate (P_2O_5)		0.2	(Khoshnevisan et al., 2013a)
(c) Potassium (K_2O)		0.2	(Pishgar-Komleh et al., 2012)
4. Biocides	kg	6.3	(Lal, 2004)

Table 3. Average technical, pure and scale efficiency of eggplant farmers.

Particular	Technical efficiency	Pure technical efficiency	Scale efficiency
Average	0.771	0.956	0.806
SD	0.13	0.12	0.13
Min	0.41	0.67	0.44
Max	1	1	1

Table 4. Optimum energy requirement and saving energy for eggplant production

Input	Optimum energy requirement (MJ ha^{-1})	Saving energy (MJ ha^{-1})	Saving energy (%)	Contribution to the total savings energy (%)
1. Human labor	614.05	23.08	3.62	0.82
2. Machinery	532.26	278.67	34.36	9.85
3. Diesel fuel	5477.27	1372.14	20.03	48.49
4. Chemical fertilizers				
(a) Nitrogen	3748.66	883.31	19.07	31.21
(b) Phosphate (P_2O_5)	301.52	71.05	19.07	2.51
(c) Potassium (K_2O)	155.98	36.75	19.07	1.30
5. Biocides	246.93	164.27	39.95	5.81
6. Seed	4.20	0.52	11.08	0.02
Total energy	11080.87	2829.80	20.34	100

Table 5. Improvement of energy indices for eggplant production

Items	Unit	Present quantity	Optimum quantity	Difference (%) (%)
Energy use efficiency	–	9.03	11.34	25.58
Energy productivity	kg MJ^{-1}	1.53	1.92	25.49
Specific energy	MJ kg^{-1}	0.65	0.52	-20.00
Net energy	MJ ha^{-1}	111701.33	114531.13	2.53
Energy intensiveness	MJ $\$^{-1}$	0.93	0.74	-20.43
Direct energy[b]	MJ ha^{-1}	7486.53 (53.82%)[a]	6091.32 (54.97%)	-18.64
Indirect energy[c]	MJ ha^{-1}	6424.14 (46.18%)	4989.55 (45.03%)	-22.33
Renewable energy[d]	MJ ha^{-1}	641.84 (4.61%)	618.25 (5.58%)	-3.68
Non-renewable energy[e]	MJ ha^{-1}	13268.82 (95.39%)	10462.62 (94.42%)	-21.15
Total energy input	MJ ha^{-1}	13910.67 (100%)	11080.87 (100%)	-20.34

[a] Numbers in parentheses indicate percentage of total optimum energy requirement.
[b] Includes human labor, diesel fuel.
[c] Includes seed, chemical fertilizers, biocides, machinery.
[d] Includes human labor, seed.
[e] Includes diesel fuel, biocides, chemical fertilizers, machinery.

Table 6. Amounts of GHG emission for efficient and inefficient farmers.

Input	Present farmers (kg $CO_{2eq.}$ ha^{-1})	Optimum farmers (kg $CO_{2eq.}$ ha^{-1})	GHG reduction (kg $CO_{2eq.}$ ha^{-1})
1. Machinery	57.58	37.79	19.79
2. Diesel fuel	335.72	268.46	67.26
3. Chemical fertilizers			
(a) Nitrogen	91.04	73.68	17.36
(b) Phosphate (P_2O_5)	5.99	4.85	1.14
(c) Potassium (K_2O)	3.46	2.80	0.66
4. Biocides	21.59	12.98	8.61
Total GHG emissions	515.37	400.56	114.82

Obviously, the timely maintenance, selection standard machinery and reduction of chemical fertilizers can be reduced the total GHG emissions of eggplant production in Guilan province of Iran, significantly. Moreover, it's suggested the present farms should be closed to optimum units from the GHG emissions point of view. Furthermore, the results showed the ability of energy optimization of DEA method was acceptable for GHG emissions reduction in agricultural crops.

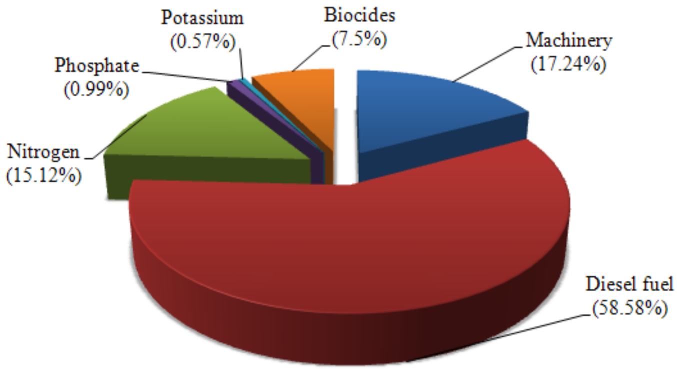

Fig. 3. Total potential reduction of GHG emission for eggplant production by DEA approach.

Khoshnevisan *et al.* (2013a) reported the DEA approach can be improved GHG emissions of cucumber production about 10181 $kgCO_{2eq.}$ ha^{-1}. Mohammadi *et al.* (2013) reported Global Warming Potential (GWP) reduction of the whole sample was obtained 11% according to DEA model results. In another study, Nabavi-Pelesaraei *et al.* (2014) presented the difference between GHG emissions of efficient and inefficient units was 2684.3 $kgCO_{2eq.}$ ha^{-1} for orange production. In other word, the total GHG emissions of orange production can be reduced about 184 $kgCO_{2eq.}$ ha^{-1} by converting inefficient to efficient units.

Conclusions

Based on the results, the following conclusions were drawn:

1- The BCC and CCR model results indicated 29, 39 and 30 units had efficient for technical, pure technical and scale efficiency, respectively.

2- The average of technical, pure technical and scale efficiency scores were found to be 0.771 (with standard deviation 0.13), 0.956 (with standard deviation 0.12) and 0.806 (with standard deviation 0.13), respectively.

3- With respect to DEA method, the total energy requirement and energy saving of eggplant production were calculated as 11080.87 and 2829.80 MJ ha^{-1}, respectively. Also, the diesel fuel and nitrogen had the highest percentage of total energy saving with 48.49% and 31.21%, respectively.

4- The energy use efficiency for the present and target units was 9.03 and 11.34, respectively. In other word the energy optimization can be improved energy ratio about 26%. Moreover, indirect and non-renewable energy had the highest reduction among all energy forms, respectively.

5- The total GHG emissions of present and optimum farms were 515.37 and 400.56 $kgCO_{2eq.}$ ha^{-1}, respectively. Also, the total GHG reduction was found about 115 $kgCO_{2eq.}$ ha^{-1}. Also, diesel fuel had the highest potential for total GHG emissions reduction by 58.58%; followed by machinery (17.24%) and nitrogen (15.12%) in eggplant production.

6- The percentage of the difference between present and target units calculated 9.93%, 11.11%, -9.42%, 2.59%, -9.49% of energy use efficiency, energy productivity, specific energy, net energy and energy intensiveness, respectively. Moreover, the direct, indirect, renewable and non-renewable energy was reduced in optimized units, significantly.

7- With respect to the above recommendation, it's suggested the energy use pattern and GHG emissions of units should be close to optimal units. For this purpose, the selection of standard machinery, timely maintenance of machinery for the reduction of diesel fuel and reduce of chemical fertilizers with using manure instead of nitrogen should be considered for eggplant production in Guilan province, Iran.

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