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Applying data envelopment analysis (DEA) to improve energy efficiency of apple fruit, focusing on cumulative energy demand

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ABSTRACT

Analysis of energy consumption provides useful information for planners and policymakers to improve the efficiency of energy consumption. Given the energy crisis which caused by the consumption of non-renewable resources in agriculture sector, a lot of attempts have been made to reduce the energy consumption of inputs as much as possible. The goal of this study is to evaluate the energy efficiency and determine the optimal pattern of input consumption and improve the efficiency in apple orchards. Based on the simple random sampling method and Cochran equation, sample size was determined as 30. Based on the results, inputs energy and output were obtained as 73092 and 59537 MJ ha^{-1}, respectively and electricity was identified as major contributor to total energy consumption with the share of 37.91% (277707 MJ ha^{-1}). Energy efficiency (ER), energy productivity (EP) and specific energy (SE) were determined as 0.82, 0.43 kg MJ^{-1} and 2.36 MJ kg^{-1}, respectively. Results showed that the total amount of cumulative energy demand is 32159.92 MJ tonne^{-1} for five environmental impact categories, of which non-renewable fossil resources had highest contribution to total cumulative energy demand (98%). Based on data envelopment analysis (DEA) results and using constant returns to scale (CRS), 9233 MJ ha^{-1} of energy could be saved, means that applying DEA can mitigate energy consumption up to 12.6% in apple orchards. Also after optimization of energy flow in orchards, energy ratio and energy productivity were improved as 12.76% and 14%, respectively.

Keywords: Apple, Cumulative Energy Demand, Data Envelopment Analysis, Energy Indices

1. Introduction

Horticultural products have a vital role in Iranian households and play an important role in Iranian economy. Apple (*M. pumila*) is one of th most consumed fruits and is a source of monosaccharides, minerals, fiber, biologically active compounds such as vitamin C and some phenolic compounds which act as natural antioxidants, so it is considered as an important part of human diet [1]. Based on FAO statistics [2], global apple production was 89.3 million tonne in 2016, which Iran was ranked as 4th apple producer in the world after Chine, Europan Union and USA with the production of 3050000 tonne.

In recnt years, enregy consumption, especially fossil fuels and chemical fertilizers has increased darmatically. It can be attributed to population growth, migration of rural labors towards the cities, restrictions on arable lands,

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low fuel and fertilizer's price, development of new technologies for production, improvement of living standards and expectations of farmers. On the other hand, excessive use of fossil fuels causes serious hazards for environment and humans. To this end, attempts should be made on reduction of energy consumption, as well as maximizing efficiency [3]. So, on of the major goals of agricultral mechanization is to optimize the use of motor power in planting, weeding and hrvesting operations by considering the energy use efficiency. It shows that the investigation and evaluation of energy flow is turned to be crucial in agricultural sector.

Cumulative energy demand (CED) is an indicator which measures the primary energy of a product or service during its life cycle, which include the consumption of direct and indirect energy. Since, most of environmntal impacts are related to the primaray energy demand, analysis of CED is served as a short form of life cycle assessment [4]. Also CED can be used as an indicator for effective screening in environmental performance [5].

Increasing energy productivity through applying optimization methods such as data envelopment analysis (DEA) causes energy saving, mitigation of environmental impacts especially greenhouse gases and increasing economic profit [6]. DEA was suggested by Charnes et al. [7] it is a non-parametric mathematical model which is widely used for measuring energy efficiency and environmental issues based on decision making units (DMUs) [8]. Some of the DEA advantages compared to parametric methods are: 1) no need to explicitly specify a mathematical form for the production function; 2) proven to be useful in uncovering relationships that remain hidden for other methodologies; 3) capable of handling multiple inputs and outputs capable of being used with any input-output measurement; 4) the sources of inefficiency can be analysed and quantified for every evaluated unit

To date, some attempts have been made for analyzing the energy consumption in apple production in Iran and world. Taghavifar and Mardani [9] determined energy ratio (ER), energy productivity (EP) and specific energy (SE) as 10.41, 0.88 kg MJ^{-1} and 1.33 MJ kg^{-1}, respectively for apple production in West Azerbaijan Province. In another study which was conducted on apple production in Tehran Province, energy input and energy output were obtained as 42819 MJ ha^{-1} and 49857 MJ ha^{-1}, respectively, which diesel fuel and manure were idetified as major contributor to total energy input with the share of 22% and 18%, respectively [10]. In Greece, C.Kehagias et al. [11] reported that in cluster 1 (consist of: three integrated orchards and four conventional orchards), apple yield and energy output had the highest value as 41189 kg.ha-1 and 98854 $MJ.ha^{-1}$, respectively. Khanali et al. [12] indicated that, the most energy consumption is related to diesel fuel with the share of 77%. Based on Longo et al. [13], preferring integrated orchards V.S. conventional orchards can to reduce the environmental pollutants. Also, preformed investigations in China, showed that the chemical fertilizers and pesticides were main share to environmental impacts on conventional apple production system [14].

Also some studies have been conducted from the prospective of CED, but there is no study on the investigation of CED trend in apple production; for example, CED indicator was investigated for open field and greenhouse tomato in seven scenarios. Results showed that CED varies between 0.8 to 160.5 per kg. Also the impact category of "non-renewable-fossil" had highest energy consumption in all scenarios [15]. Yildizhan [16] analyzed energy and cumulative exergy for open field and greenhouse tomato. Based on the results, cumulativ eneergy consumption was obtained as 6703.042 MJ t^{-1} and 4200.881 MJ t^{-1} for open field and greenhouse tomato, respectively. Highest cumulative energy consumption was related to Nitrogn fertilizer (48%). In a study which was conducted on exergy analysis of open field and greenhouse tomato production in Tokat and Antalya, Turkey, respectively, the highest cumulative exergy consumption was related to the irrigation water and eelectricity for open field and greenhouse, respectively [17].

Based on the statistics, Aligudarz region produces 80% of apple in Lorestan Province and 4% of apple in Iran [18]. According to previous study, Authors didn't find comprehansive study on the analysis of energy flow with the focus on CED in apple production in Iran. Therefore, novelty of this paper was evaluation of apple production system energy by CED indicators. General objectives of this study are as follows:

- Estimation the energy indices such as ER, EP and SE in fruit apple production of Aligudarz region, Iran.
- Evaluation of energy quantities based on CED method.
- Determine efficient and inefficient units of energy consumption by DEA technique.
- Explanting some strategies in order to reduce energy consumption in apple production.

Nomenclature

CED	Cumulative Energy Demand
CRS	Constant Returns to Scale
DEA	Data Envelopment Analysis
DMU	Decision Making Unit
ER	Energy Ratio
EP	Eutrophication Potential
EP	Energy Productivity
FAO	Food and Agriculture Organization
PTE	Pure Technical Efficiency
SE	Specific Energy
SE_f	Scale Efficiency
TE	Technical Efficiency
VRS	Variable Returns To Scale

2. Materials and Methods

2.1. Production process and weather conditions for apple fruit

Apple orchards have higher quality in highland with cold weather in comparison with lowlands and are less susceptible to pests and diseases. Ripening time of apple varies between 70 to 180 days. Due to genetic variation of apple, it is difficult to determine specific climatic requirements, but average chilling requirement is 1600 hours below 7°C. Apple varieties differ in final product and tree size, even when grown from same underground stem. If there is no pruning plan for apple trees, the trees especially in some varieties will overgrow, so make apple harvesting difficult. Tree are usually pruned in late fall, after defoliation or in early spring, before tree leaf emergence. The first round of irrigation begins at the time of flowering and is completed after fruit harvesting. Trees are irrigated in both drip and flooded methods and based on available water, time interval of irrigation varies between 7 to 14 days. Harvesting season starts in mid-September and continues until late November and sometimes until mid-December. Average apple tree yield is 120 kg [19].

2.2. Geographical location of study area and data collection

Present study was conducted during 2018-19 cropping season in Aligudarz county, located in south-eastern of Lorestan province (33°24′ N/49°42′E) (Fig. 1). Aligudarz with the area and latitude of 5870 km^2 and 2022 m above the sea level, respectively, has the population of 140275. Out of 4800 ha orchard area in the region, 1000 ha is fertile. The major horticultural crops are walnut, apple, almond, peach and nectarine [20].

Required data were collected through questionnaire and face-to-face interview with agriculture Jihad experts and apple growers. Simple random sampling method was used for determining sample size [21]:

$$n = \frac{Nt^2S^2}{Nd^2 + t^2S^2} \tag{1}$$

where n is sample size, N is statistical population size, t is acceptable coefficient of confidence, S^2 is the variance of intended trait and d is acceptable error. t, S^2 and d were considered as 1.96, 0.5 and 0.05, respectively. Accordingly, sample size was determined as 30 and questionnaires were randomly distributed between apple growers. Required data which were extracted from questionnaires included amount, number and the frequency of inputs consumption such as agricultural machinery, chemical fertilizers, pesticides, human labor, diesel fuel, irrigation water and electricity and also yield of apple fruit.

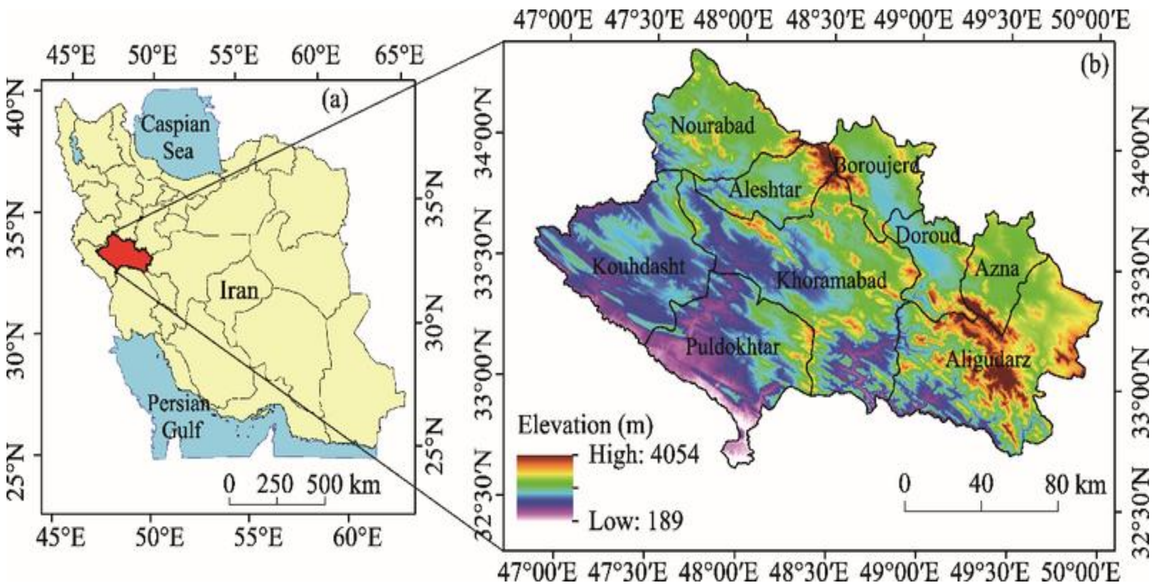

Fig.1. Location of the studied region in the west of Iran

2.3. Calculation of energy indices in apple production

Comparison of different production systems and improvement of energy use efficiency can be facilitated using three energy indicators including Energy Ratio (ER), Energy Productivity (EP) and Specific Energy (SE), which are calculated through following equations [10]:

$$\text{Energy Ratio} = \frac{\text{Energy output (MJ.ha}^{-1})}{\text{Energy input (MJ.ha}^{-1})} \tag{2}$$

$$\text{Energy Productivity (kg MJ}^{-1}) = \frac{\text{Apple fruit Yield (kg.ha}^{-1})}{\text{Energy input (MJ.ha}^{-1})} \tag{3}$$

$$\text{Specefic Energy (MJ kg}^{-1}) = \frac{\text{Energy input (MJ.ha}^{-1})}{\text{Apple fruit Yield (kg.ha}^{-1})} \tag{4}$$

ER is the ratio of energy output to energy inputs. This indicator shows the effect of one unit of energy input on the production of one unit energy output. EP represents the amount of output per unit of energy input. EP depends on type of crop, time and location. This indicator can be used to evaluate how energy is used in different production systems. SE is the inverse of EP and shows energy consumption per one kg of output [22]. The total energy inputs was obtained from sum of energy of each input used for apple production. Energy equivalent of each input is obtained based on eq. 5 suggested by Kitani [23]:

$$E_{input} = I_{consumption} \times ec_{input} \tag{5}$$

where E_{input} is the input energy (MJ ha^{-1}), $I_{consumption}$ is input consumption (unit ha^{-1}) and ec_{input} is energy content of inputs (MJ $unit^{-1}$). Average consumption of inputs and their energy equivalent are presented in Table 1.

2.4. Cumulative energy demand (CED)

CED indicator is an approach to evaluate a system sustainability in terms of energy. Actually this indicator describes the total required primary energy to extract, produce, use and sell a product [4]. Total energy consumption during the life cycle of a production system includes the consumption of direct and indirect energy. Direct energy is related to the operations for crop production such as land preparation, irrigation, fuel, electricity, harvesting and inputs transportation and indirect energy is related to seeds, machinery and agrochemicals [26].

Table 1. Energy equivalents and average quantity of inputs and output in apple fruit production.

Items (Unit)	Energy equivalent ($MJ\ unit^{-1}$)	Average quantity ($Unit\ ha^{-1}$)	References
A. Inputs			
1. Human labor (hr)	1.96	4931.12	(Rafiee et al., 2010)
2. Machinery (hr)	64.8	31335.26	(Singh et al., 2004)
3. Water (m^3)	1.02	824.50	(Rafiee et al., 2010)
4. Diesel fuel (L)	56.31	284.67	(Singh et al., 2004)
5. Electricity (kwh)	3.6	7696.38	(Ozkan et al., 2004)
6. Chemical fertilizers (kg)			
6.1. Nitrogen	78.1	97.5	(Kitani, 1999)
6.2. Phosphate	13.7	178.24	(Ozkan et al., 2004)
6.3. Potassium	11.15	180.98	(Ozkan et al., 2004)
7. Manure (kg)	0.31	12141.93	(Taghavifar & Mardani, 2015)
8. Chemicals (kg)			
8.1. Insecticides	101.2	3.70	(Rafiee et al., 2010)
8.2. Fungicides	216	2.04	(Rafiee et al., 2010)
8.3. Herbicides	238.00	3.40	(Kitani, 1999)
B. Output			
Apple fruit	1.9	31335.26	(Rafiee et al., 2010)

In the other hand, in terms of energy sources, CED indicator is classified into two groups as renewable and non-renewable. Renewable category includes biomass, wind, solar, geothermal, water energy resources and non-renewable category includes fossil fuels and forests (Table 2). Table 3 represents the coefficients of CED indicator (for renewable and non-renewable energy resources) for each inputs used in apple production in Aligudarz region (extracted from Simapro V.8.2.3.0).

2.5. Data envelopment analysis (DEA)

DEA is a data mining method, which ranks production systems based on their performance. Each production unit is known as a DMU. An inefficient DMU can be converted to an efficient one through decreasing input consumption and keeping output constant (input-oriented model) at the same time [28]. Since, apple growers play major role in determining the rate of inputs consumption and also, energy output's dependency on different factors, in the present study, input-oriented modeling approach was used. The efficiency of DEA units is determined based on the constant returns to scale (CRS) [7] and variable returns to scale (VRS) [8] and efficiency score is determined in the form of Technical Efficiency (TE), Pure Technical Efficiency (PTE) and Scale Efficiency (SE_f):

2-5-1- Technical Efficiency

Based on eq. 6, TE is defined as the ratio of the sum of the weighted outputs to the weighted inputs. TE of efficient units is 1, it means that the output is on the boundary of production function and there is no potential for mitigating the inputs consumption. TE less than 1 shows inefficiency of inputs consumption in DMU [7]:

$$Max\ h_k = \frac{\sum_{r=1}^{s}(u_{rk}y_{rk})}{\sum_{i=1}^{m}(v_{ik}x_{ik})} \tag{6}$$

Subject to:

$$\frac{\sum_{r=1}^{s}(u_{rk}y_{rk})}{\sum_{i=1}^{m}(v_{ik}x_{ik})} \leq 1; \quad j = 1, \dots, n$$

$$u_{rk}, y_{rk} \geq 0; \qquad r = 1, \dots, s; \quad i = 1, \dots, m$$

where k donates inputs, y is output, m and s are the number of inputs and outputs, respectively, in DMU and v_{ik} and u_{rk} are the weights matrix of inputs and outputs, respectively.

2.5.2. Pure Technical Efficiency

PTE is calculated based on the VRS model. Accordingly, in this model, PTE is the TE which is estimated based on VRS for each

Table 2. Characteristic factors classification of cumulative energy demand impact (Renewable Energy and Energy Efficiency Organization, 2019).

Categories	Subcategory	Items
Renewable Energy (RE)	Biomass	Wood, Food products, Agricultural biomass
	Wind	Wind energy
	Solar	Solar energy (heat and electricity)
	Geothermal	Geothermal energy (shallow: 300-1000 mm)
	Water	Hydropower energy
Non-renewable Energy (NRE)	Fossil energy	Coal, lignite, crude oil, natural gas
	Forests	Wood & biomass from primary forests

Table 3. The coefficients of cumulative energy demand for each one of consumption inputs in apple production.

Inputs	Non-renewable resources: fossil (MJ)	Non-renewable resources: nuclear (MJ)	Non-renewable resources: biomass (MJ)	Renewable resources: biomass (MJ)	Renewable resources: wind, solar, geothermal (MJ)	Renewable resources: Water (MJ)
Nitrogen fertilizer (kg)	32.50	0.88	0.0004	0.360	0.050	0.335
Phosphate fertilizer (kg)	41.50	3.89	0.0970	1.330	0.233	1.520
Potassium fertilizer (kg)	32.80	2.47	0.0018	2.990	0.127	0.747
Manure (kg)	323.00	45.40	45.4000	11.950	3.340	16.500
Agricultural machinery (kg)	19.00	1.75	0.0004	0.597	0.106	0.926
Total Insecticides (kg)	14.00	1.78	0.0007	0.414	0.100	0.605
Total herbicides (kg)	4.36	0.41	0.00008	0.096	0.022	0.131
Total fungicides (kg)	8.50	2.11	0.0002	0.220	0.680	0.412
Electricity (kwh)	1710.15	0	0.0000	0	0	0
Diesel fuel (l)	29600.69	164.05	0.1260	35.700	8.510	50.600
Direct energy in orchard	0	0	0	0	0	0

DMU [8] and is affected by SE_f. PTE as an advantage, compares inefficient DMUs with efficient ones under the same environmental and geographical conditions [29]. This model is calculated based on Eq. (7) [8]:

$$Max\ z = uy_j - u_j \quad (7)$$

Subject to:

$$vX_i = 1;\ -vX + uY - u_0 e \leq 0$$

where x and y are model input and output, respectively, u_0 and z are weights matrices of model inputs and output, respectively.

2.5.3. Scale Efficiency

TE and SE_f are calculated using CRS model; while VRS model calculates PTE for DMUs. In this study, TE and PTE were calculated based on CRS and VRS models, respectively and then SE_f was estimated through Eq. (8) [30]:

$$\text{SEf} = \frac{\text{TE}}{\text{PTE}} \quad (8)$$

This study aimed to improve the efficiency of apple production through optimization of input consumption in Aligudarz region, Iran. To this end, primary data were prepared and organized in Excel 2016 and then were analyzed using DEA Solver V1.3 to improve energy use efficiency for each input in the study area. Finally, efficient and inefficient units were determined and energy consumption and energy indices were calculated after optimization of inefficient DMUs.

3. Results and Discussions

3.1. Analysis of energy consumption and energy indices in apple production

The amount of energy input, output, and energy indices per ha of apple orchards in

Aligudarz region, Iran are presented in Table 4. Based on the results, the total energy input and output was 73092 and 59537 MJ ha^{-1}, respectively. Energy output is equal to 31335 kg of harvested apple per ha. As can be seen in Table 4, electricity had the highest contribution to total energy consumption (37.91%) in apple production. Electricity is used for pumping irrigation water. This high contribution can be attributed to water extraction from the wells, inefficient irrigation systems and using obsolete electric motors in the study area. So in this regard, reconsidering the water supply systems seems to be necessary. Diesel fuel was identified as the second contributor to energy consumption after electricity (21.93%). Diesel fuel is used in orchard tillers and tractors for fertilization, crust-breaking of soil, mechanical control of weeds, spraying etc. and this high contribution shows inefficient use of diesel fuel in machinery. Kehagias et al. [11] identified diesel fuel as one of the major contributors to total energy consumption with the share of 35% (38175 MJ ha^{-1}) in Greek apple orchards. Khanali et al. [12] reported the diesel share in total energy consumption as 78% (68980 MJ ha^{-1}) for apple production in West Azerbaijan province, Iran.

About other inputs, the contribution of fertilizers, human labor, manure, pesticides, tractor and machinery and irrigation water were determined as 16.52, 13.22, 5.15, 2.22, 1.89 and 1.15%, respectively. Based on the results, high consumption of fertilizers can cause some environmental hazards. Therefore, green fertilizers can be considered as an energy- and cost-saving alternative for chemical fertilizers. Based on Baldini et al. [31], fuel and chemical fertilizers were identified the most energy-consuming inputs Italy with the share of 46.6 and 20.9%, respectively. The apple orchard's yield in study area was higher than those observed in literature, and consequently higher energy consumption was observed.

Energy indices were used to determine the relations between energy input and output. Results showed that ER with the average of 0.82, varies between 0.66 and 1.03 for 30 apple growers; it means that in average, energy output is 0.82 MJ per 1 MJ of energy input. The average of EP index was obtained as 0.43 kg MJ^{-1}, meaning that 0.43 kg apple is produced per MJ of energy consumption, while it varies between 0.34 and 0.54 kg MJ^{-1}. About SE index, it was obtained as 2.36 MJ kg^{-1} which indicated the required energy for production of 1 kg apple. In the studies which were conducted in Iran and Europe, ER, EP and SE indices were respectively obtained as 0.9, 0.4 kg MJ^{-1} and 2.6 MJ kg^{-1} in Greece [11], 1.51, 0.63 kg MJ^{-1} and 1.59 MJ kg^{-1} in Turkey [32], 1.16, 0.49 kg MJ^{-1} and 2.06 MJ kg^{-1} in Iran [10]. Based on the results obtained from present study, ER for apple production of study area was less than those obtained from other studies in literature and it can be attributed to the higher energy input in study area.

3.2. determination of consumed energy type based on cumulative energy demand in apple production

Table 5 shows CED for environmental impact categories in apple production. Based on these results, the total CED for all impact categories was determined as 32159.92 MJ t^{-1}, which non-renewable energy resources (fossil) had highest CED with the amount of 31800.40 MJ t^{-1} (98% of total energy consumption). The production of diesel fuel and its transportation to apple orchards (for tractor and agricultural machinery) was identified as major contributor to total consumption of non-renewable energy (29600 MJ). In this regard, applying new tractors and implements can be a potential alternative for outdated ones to reduce fuel consumption and consequently energy consumption. In addition, increasing investment and utilization of renewable energy sources such as solar energy and clean fuels may be another effective way to reduce fossil fuels in the study area. As can be seen, diesel fuel was identified as major contributor to total energy consumption in other impact categories (Table 5). Another energy-intensive input was manure which had a major contribution on nonrenewable-nuclear (20%), renewable-biomass (22%), renewable-wind, geothermal and

Table 4. Consumption energy values and energy indices in apple fruit production

Items	Energy (MJ ha^{-1})			
	Min	Average	Max	(Share of energy %)
A. Inputs energy				
1. Human labor	4308	9665	14998	13.22
2. Machinery	1223	1384	1630	1.89
3. Water	714	841	959	1.15
4. Diesel fuel	11262	16030	20272	21.93
5. Electricity	18000	27707	37656	37.91
6. Chemical fertilizers				
6.1. Nitrogen	3773	7615	10780	10.42
6.2. Phosphate	1522	2442	3425	2.76
6.3. Potassium	1115	2018	2788	3.34
7. Manure	1819	3764	9699	5.15
8. Chemicals				
8.1. Insecticides	289	375	434	0.51
8.2. Fungicides	309	441	617	0.60
8.3. Herbicides	595	811	1020	1.11
Input energy total	59230	73092	91390	100
B. Output energy				
Apple fruit	41800	59537	76000	100
C. Energy indices				
1. Energy ratio	0.66	0.82	1.03	
2.Energy productivity (kg / MJ)	0.34	0.43	0.54	
3. Specific energy (MJ/ kg)	1.80	2.36	2.93	

renewable-water (24%) that is due to indiscriminate use of this input in apple orchards of study area. Based on Ntinas et al. [15] who conducted a study on open-field tomato, nonrenewable energy resources-fossil was identified as major contributor to CED. This emphasizes the use of renewable energy sources as fuel in different production systems and services.

3.3. improvement of energy consumption and energy indices using DEA

Table 6 and Fig. 2 show efficiency scores calculated based on CRS and VRS for each unit (apple orchard). For example, TE equal to 0.91 for unit 13 indicates that amount of energy input consumption in this unit can be mitigated by 9% (efficiency point) without any reduction in the output. In the other hand,

Table 5. Quantities of energy based on cumulative energy demand method in apple fruit production.

Categories (MJ)	Cumulative energy demand (for 1 tonne of apple fruit)	The most effective input (share of each one (%))
Non-renewable resources: fossil	31800.40	Diesel fuel (98%)
Non-renewable resources: nuclear	222.14	Diesel fuel (74%), Manure (20%)
Non-renewable resources: biomass	0.233	Diesel fuel (56%), Phosphate (42%)
Renewable resources: biomass	56.63	Diesel fuel (67%), Manure (22%)
Renewable resources: wind, solar, geothermal	12.51	Diesel fuel (68%), Manure (27%)
Renewable resources: Water	71.62	Diesel fuel (70%), Manure (24%)

it shows the potential of each unit for reduction of inputs consumption (1- θ) without any reduction in their output. θ denotes the efficiency score of an inefficient unit. Based on the results, PTE, TE and SE_f were obtained as 0.98, 0.97 and 0.95, respectively (Table 6). In the other hand, based on VRS model, 21 units (70% were identified as efficient units (PTE=1). It was 10 units (33%) for CRS model (TE=1). Inefficiency in units with TE and PTE less than 1 can be attributed to the scale of production system and inefficient inputs management (such as units 1, 2, 4, 5 etc. which have TE and PTE less than 1). Khoshnevisan et al. [33] determined TE, PTE and SE_f as 0.78, 0.89 and 0.86, respectively for wheat production in Isfahan province of Iran.

If the efficiency score of a unit is 1 based on both CRS and VRS models (TE, PTE=1), it will have highest efficiency scale (SE_f=1) (units 7, 9, 11 etc.). Also the units with PTE=1 and TE<1 are locally efficient and are not totally efficient (units 3, 8, 10, 16 etc.). According to above, 33.3% of orchards (10 units) have SE_f=1, 36.7% (11 units) are locally efficient and 30% (9 units) are inefficient units. When the production unit has PTE = 1, the return to scale is determined by the output weight; if it is less than 0, so return to scale will be increasing, if it is greater than 0, return to scale will be decreasing and equal to 0 will be constant return to scale. For example, as can be seen in Table 6, return to scale for units 1 to 5 is increasing, while it decreasing for units 7, 9, 11 and 12.

In order to identify best apple growers and determine the highest referencing inefficient units to efficient ones, Benchmark and CRS methods were used, respectively. As can be seen in Table 7, units 7, 9 and 17 were identified as the most efficient units with referred number of 8. These 3 units can be good models for referring inefficient units. Also, if inefficient units are referred to efficient ones with a certain degree of probability, they will turn to be efficient in terms of inputs consumption. For instance, inefficient unit 1 can be an efficient one through referring to efficient units 11, 12 and 20 with the probability of 0.71, 0.24 and 0.02, respectively and using their recommendations for reducing input consumption (without reduction in output). This information can be seen in Benchmark column of Table 7 in detail.

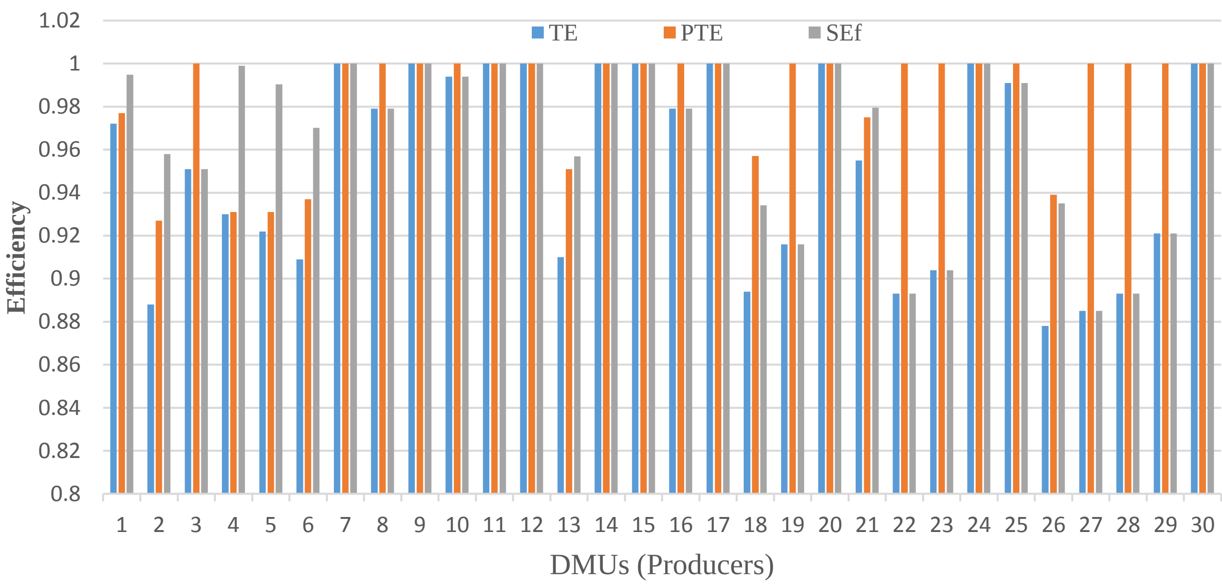

Fig. 2. Efficiency score distribution of apple fruit producers in Aligudarz region.

Table 6. Pure Technical, technical and scale efficiencies and returns to scale.

DMUs	TE	PTE	SEf	Return to scale
1	0.972	0.977	0.995	Increasing
2	0.888	0.927	0.958	Increasing
3	0.951	1.000	0.951	Increasing
4	0.930	0.931	0.999	Increasing
5	0.922	0.931	0.990	Increasing
6	0.909	0.937	0.970	Increasing
7	1.000	1.000	1.000	Constant
8	0.979	1.000	0.979	Increasing
9	1.000	1.000	1.000	Constant
10	0.994	1.000	0.994	Increasing
11	1.000	1.000	1.000	Constant
12	1.000	1.000	1.000	Constant
13	0.910	0.951	0.957	Increasing
14	1.000	1.000	1.000	Constant
15	1.000	1.000	1.000	Constant
16	0.979	1.000	0.979	Increasing
17	1.000	1.000	1.000	Constant
18	0.894	0.957	0.934	Increasing
19	0.916	1.000	0.916	Increasing
20	1.000	1.000	1.000	Constant
21	0.955	0.975	0.979	Increasing
22	0.893	1.000	0.893	Increasing
23	0.904	1.000	0.904	Increasing
24	1.000	1.000	1.000	Constant
25	0.991	1.000	0.991	Increasing
26	0.878	0.939	0.935	Increasing
27	0.885	1.000	0.885	Increasing
28	0.893	1.000	0.893	Increasing
29	0.921	1.000	0.921	Increasing
30	1.000	1.000	1.000	Constant
Mean	0.950	0.980	0.970	Increasing
Max	1.000	1.000	1.000	
Min	0.878	0.927	0.885	
SD	0.046	0.026	0.038	

Table 7. Results of technical efficiency analysis.

DMU (apple fruit producers)	TE score	Frequency in referent set	Benchmarks	Rank of DMU
1	0.972	-	11 (0.71)- 12 (0.24)- 20 (0.02)	
2	0.888	-	11 (0.65)- 12 (0.22)- 20 (0.02)	
3	0.951	-	11 (0.24)- 12 (0.30)- 20 (0.32)	
4	0.930	-	11 (0.52)- 12 (0.12)- 14 (0.08)- 24 (0.23)	
5	0.922	-	11 (0.13)- 12 (0.54)- 14 (0.31)	
6	0.909	-	11 (0.35)- 14 (0.53)	
7	1.000	1	-	8
8	0.979	-	14 (0.70)	
9	1.000	1	-	8
10	0.994	-	12 (0.56)- 15 (0.26)- 24 (0.05)	
11	1.000	18	-	1
12	1.000	13	-	2
13	0.910	-	11 (0.85)	
14	1.000	8	-	3
15	1.000	2	-	7
16	0.979	-	11 (0.39)- 20 (0.49)	
17	1.000	1	-	8
18	0.894	-	11 (0.15)- 12 (0.29)- 20 (0.43)	
19	0.916	-	11 (0.25)- 12 (0.39)- 20 (0.03)- 20 (0.14)	
20	1.000	8	-	3
21	0.955	-	11 (0.52)- 12 (0.36)- 30 (0.06)	
22	0.893	-	11 (0.68)	
23	0.904	-	11 (0.60)	
24	1.000	6	-	5
25	0.991	-	14 (0.79)	
26	0.878	-	11 (0.68)- 12 (0.17)- 30 (0.03)	
27	0.885	-	11 (0.77)	
28	0.893	-	11 (0.68)	
29	0.921	-	11 (0.24)- 12 (0.47)- 20 (0.03)	
30	1.000	3	-	6

The optimized amounts of each input are calculated through multiplying the efficiency of each unit by the amount of inputs consumption. The analysis of inputs consumption in inefficient units, before and after optimization are presented in Table 8. Accordingly, total energy inputs was obtained as 73092 and 63859 MJ ha^{-1}, before and after optimization of inefficient units, respectively. It is important to note that due to the using input-oriented CCR model in this study, the output deficiency is considered to be zero. Also the amount of input mitigation in inefficient units for making them efficient can be seen in Table 8. For example, the reduction amount of inputs such as fertilizers, pesticides, electricity, manure, diesel fuel, irrigation water, human labor, machinery and total energy input was obtained as 1886, 421, 4480, 988, 1420, 268, 4200, 254 and 13916 MJ ha^{-1} in the unit 13 with efficiency score of 0.91 (TE=0.91). Fig. 3 shows the contribution of ach inputs to energy saving after optimization. Based on the results, electricity had highest energy saving with reduction of 3628 MJ ha^{-1} (39%) in comparison with other inputs. As mentioned before, electricity is used for setting up the electric motors, extracting water from wells and pumping irrigation water to orchard. Applying obsolete electric pumps dramatically increase energy consumption as well as energy losses.

Applying inefficient traditional irrigation methods causes water and electricity losses, depletion of groundwater, increasing the depths of deep wells for groundwater extraction, and using obsolete water extraction equipment results in increased electricity consumption in the orchards. Human labor was identified as another major input which has high potential for reduction with 2625 MJ.ha^{-1} (29%). Totally, energy-saving potential in apple orchard is about 9233 MJ ha^{-1} (12.6%). In a study that was conducted to improve energy efficiency for orange in Guilan province, Iran, 12.9% of energy input can be saved by optimization of energy consumption [34]. Also, by optimization of energy input in grape production in Arak county, Iran, reduced energy consumption from 29636 to 26000 MJ ha^{-1} (11%) [35]. Mousavi-Avval et al. [28] showed that the electricity, pesticides and fertilizers with the reduction of 23.07, 18.23 and 9.12, respectively, had highest potential for reduction in apple production in Tehran province, which is in agreement with findings of this study.

Energy indices have been presented in Fig.4, before and after optimization. Accordingly, ER, EP and SE reduced from 0.82, 0.43 kg MJ^{-1} and 2.36 MJ kg^{-1} to 0.94, 0.5 kg MJ^{-1} and 2.03 MJ kg^{-1}, respectively. Results showed that after optimization of energy flow, ER and EP were increased by 12.76 and 14%, respectively, while SE index was reduced by 16.25%. Mousavi-Avval et al. [28] reported that ER, EP and SE indices could be improved by 13% (1.31), 12.2% (0.55 kg MJ^{-1}) and 11.2% (1.83 MJ kg^{-1}) after optimization with DEA method in apple production in Tehran province. The improvement of these indices (ER, EP and SE) for orange production in Iran was obtained as 14.7, 14.4 and 12.6%, respectively [34].

Although these values have improved, the extent of improvement of these indices may be different from those of other studies. This difference is attributed to the applied nature of DEA method which make benchmarks based on the units in study area and inefficient units are investigated relative to these units.

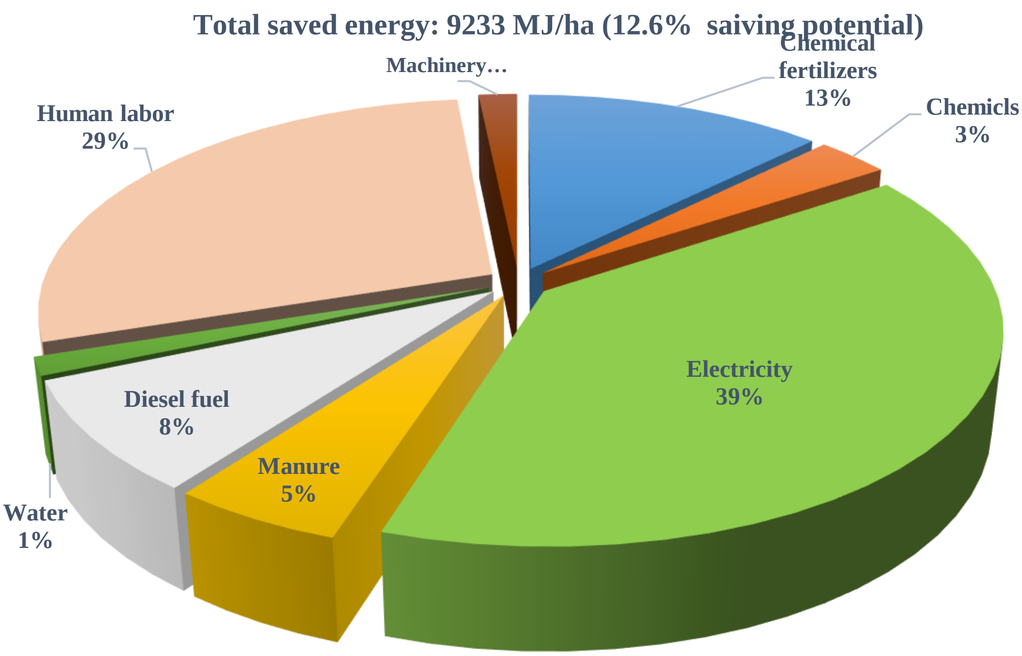

Fig.3. The contribution of saving energy from different sources in apple fruit production.

Table 8. The actual energy consumption and improved energy for apple fruit inefficient producers based on the results of CRS model.

DMU	TE	Actual energy ($MJha^{-1}$)									Improved energy ($MJha^{-1}$)								
		Chemical fertilizers	**Manure**	**Chemicals**	**Electricity**	**Diesel**	**Water**	**labor**	**Machinery**	**Total**	**Chemical fertilizers**	**Manure**	**Chemicals**	**Electricity**	**Diesel**	**Water**	**labor**	**Machinery**	**Total**
1	0.972	12516	4243	1551	26280	16893	867	7940	1442	71732	12029	4123	1367	24835	16415	748	4857	1401	65775
2	0.888	12516	4243	1789	29520	16893	857	14996	1442	82256	10998	3769	1250	22706	15008	684	4440	1281	60137
3	0.951	11274	3031	1789	23400	14078	816	7936	1317	63640	10485	2883	1358	22200	13390	714	7548	1152	59728
4	0.930	12539	3789	1677	31050	18301	893	9408	1489	79145	11659	3523	1412	27346	17016	745	7044	1384	70130
5	0.922	12384	4041	1611	28000	18770	884	8803	1463	75956	11334	3727	1486	25822	17280	756	6001	1349	67755
6	0.909	11401	9699	1789	28080	18019	918	14998	1630	86534	10359	3842	1289	25232	16372	711	5760	1280	64846
8	0.979	8058	3940	1789	27000	14641	836	7938	1379	65582	7892	2970	1086	21430	13796	585	5558	1009	54326
10	0.994	10716	2728	1342	23220	15204	877	7933	1223	63252	10378	2712	1334	20387	14935	686	5894	1153	60179
13	0.910	12516	4850	1551	26280	15767	918	7942	1505	71328	10630	3862	1130	21800	14347	650	3742	1251	57413
16	0.979	12516	3031	1789	33840	13514	918	14998	1379	81986	11029	2967	1397	23446	13231	769	9066	1191	63096
18	0.894	15645	3031	1812	31500	14781	956	9771	1332	78829	10629	2710	1421	22676	13214	743	8735	1146	61274
19	0.916	10583	3031	1542	29077	15160	745	6243	1302	67685	9692	2776	1230	21755	13883	620	5717	1124	56799
21	0.955	12516	4041	1563	28800	16893	816	5578	1400	71607	11597	3859	1379	24056	16133	724	5304	1337	64390
22	0.893	11274	3637	1551	30960	12951	918	7924	1379	70594	8573	3114	912	17581	11571	524	3018	1009	46301
23	0.904	12516	4547	1331	27000	11262	765	4308	1473	63202	7544	2741	802	15471	10182	461	2656	888	40745
25	0.991	8940	3464	2071	29314	16089	801	11001	1344	73024	8858	3334	1219	24054	15486	657	6239	1133	60978
26	0.878	13574	4294	1472	27300	16893	850	6694	1437	72515	10829	3772	1219	22332	14837	669	4351	1262	59271
27	0.885	11274	4243	1551	23544	14641	714	7916	1442	65325	9601	3488	1021	19691	12959	587	3380	1130	51857
28	0.893	11274	3637	1551	26172	12951	745	7911	1379	65319	8573	3114	912	17581	11571	524	3018	1009	46301
29	0.921	12516	3031	1789	20160	13514	816	14990	1254	68070	8913	2792	1112	18570	12448	567	4156	1025	49581
Mean	0.950	12075	3764	1626	27707	16030	841	9665	1384	73092	10910	32081	1341	24080	15258	715	7040	1234	63859

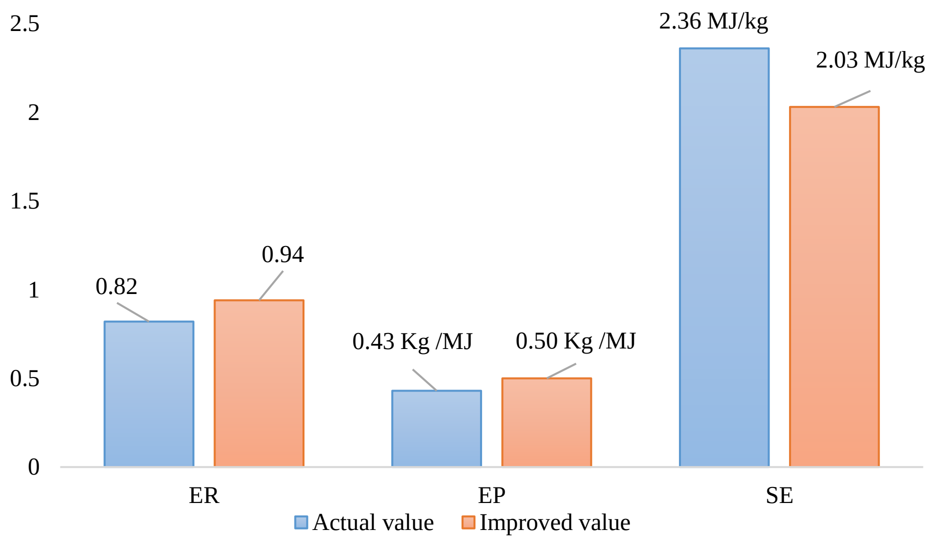

Fig.4. Improvement of energy indices for apple fruit production.

4. Conclusion

One of the ways for optimal allocation of inputs is the comparison of inefficient production units with efficient ones. It can provide a basis for improving productivity of production units. DEA method can be used for identifying the efficient units. In this regard, the present study aimed to investigate the efficiency of apple production in west of Iran (Aligudarz county, Lorestan province). Energy input of apple production was determined as 73092 and 63859 MJ ha^{-1} before and after energy flow optimization, respectively. Results showed that electricity is major contributor to total energy consumption with the consumption of 27707 MJ ha^{-1} (37.91%), also diesel fuel and fertilizer were identified as the energy-intensive inputs with the contribution of 21.93 and 16.52%, respectively. Based on the results, highest energy saving was related to the electricity with the reduction of 3628 MJ ha^{-1} (39%). The contribution of non-renewable energy to total energy consumption was determined as about 80.5% which, was related to electricity, diesel fuel and fertilizers. It means that apple orchards are highly dependent on non-renewable energy resources, which indicates environmental unsustainability in apple production. Because energy generation, transportation and consumption cause environmental consequences. So high energy consumption and low efficiency in apple orchards can be attributed to the applying obsolete and inefficient water pumps, lack of proper management for using fertilizers and pesticides, applying agricultural machinery for land preparation, frequency of pesticides application and transportation. Therefore, proper and comprehensive management of inputs and applying the mechanization with considering all its aspects can improve energy use efficiency without any reduction in output and profitability.

References

[1] Wu, J., Gao, H., Zhao, L., Liao, X., Chen, F., Wang, Z. & Hu, X. (2007). Chemical compositional characterization of some apple cultivars. Food Chemistry. 103(1): 88-93.

[2] Food and Agriculture Organization (FAO). www.fao.org, 2018.

[3] Erdal, G., Esengün, K., Erdal, H. & Gündüz, O. (2007). Energy use and economical analysis of sugar beet

production in Tokat province of Turkey. Energy. 32(1): 35-41.

[4] Frischknecht, R., Wyss, F., Knöpfel, S. B., Lützkendorf, T. & Balouktsi, M. (2015). Cumulative energy demand in LCA: the energy harvested approach. The International Journal of Life Cycle Assessment. 20(7): 957-969.

[5] Huijbregts, M. A., Hellweg, S., Frischknecht, R., Hendriks, H. W., Hungerbuhler, K., & Hendriks, A. J. (2010). Cumulative energy demand as predictor for the environmental burden of commodity production. Environmental science & technology, 44(6): 2189-2196.

[6] Schnapp, R. (2012). Energy statistics for energy efficiency indicators. Joint Rosstat—IEA Energy Statistics Workshop Moscow.

[7] Charnes, A., Cooper, W. W. & Rhodes, E. (1978). Measuring the efficiency of decision making units. European journal of operational research. 2(6): 429-444.

[8] Banker, R. D., Charnes, A. & Cooper, W.W. (1984). Some models for estimating technical and scale inefficiencies in data envelopment analysis. Management science. 30(9): 1078-1092.

[9] Taghavifar, H. & Mardani, A. (2016). Prognaostication of energy consumption and greenhouse gas (GHG) emission analysis of apple production in West Azarbayjan of Iran using Artificial Neural Network. Journal of Cleaner Production. 87: 159- 167.

[10] Rafiee, S., Mousavi Avval, S. H. & Mohammadi, A. (2010). Modeling and sensitivity analysis of energy inputs for apple production in Iran. Energy. 35: 3301–3306.

[11] C. Kehagias, M., C. Michos, K., C. Menexes , G., P. Mamolos, A., A. Tsatsarelis, C., D. Anagnostopoulos, C. & L. Kalburtji, K. (2015). Energy equilibrium and Carbon dioxide, Methane, and Nitrous oxide-emissions in organic, integrated and conventional apple orchards related to Natura 2000 site. Journal of Cleaner Production. 91: 89-95.

[12] Khanali, M., Kokei, D., Aghbashlo, M., Keyhani Nasab, F., Hosseinzadeh-Bandbafha, H., Tabatabaei, M. (2020). Energy flow modeling and life cycle assessment of apple juice production: Recommendations for renewable energies implementation and climate change mitigation. Journal of Cleaner Production. 246:118997.

[13] Longo, S., Mistretta, M., Guarino, F., Cellura, M. (2016). Life Cycle Assessment of organic and conventional apple 393 supply chains in the North of Italy. Journal of Cleaner Production. 56: 1-10.

[14] Zhu, Z, Jia, Z., Peng, L, Chen, Q., Yuanmao, H., Shunfeng, J. (2018). Life cycle assessment of conventional and organic apple production systems in China. Journal of Cleaner Production. 201: 156-168.

[15] Ntinas, G. K., Neumair, M., Tsadilas, C. D. & Meyer, J. (2017). Carbon footprint and cumulative energy demand of greenhouse and open-field tomato cultivation systems under Southern and Central European climatic conditions. Journal of cleaner production. 142 (4): 3617-3626.

[16] Yildizhan, H. (2018). Energy, exergy utilization and CO2 emission of strawberry production in greenhouse and open field. Energy. 143: 417-423.

[17] Yildizhan, H. & Taki, M. (2018). Assessment of tomato production process by cumulative exergy consumption approach in greenhouse and open field conditions: Case study of Turkey. Energy. 156: 401-408.

[18] Anonymous (2016). Statistical Yearbook of Lorestan province in Iran, Available from: amar.org.ir/ English/IranStatistical-Yearbook [In Persian].

[19] Yepsen, R. (1994). Apples. New York: W.W. Norton & Co. ISBN 0-393-03690-1.

[20] Anonymous (2018). Statistical Yearbook of Lorestan province in Iran. Amar.org.ir.

[21] Cochran, W.G. (1977). Sampling Techniques, third ed. John Wiley & Sons, New York. USA.

[22] Chang, M. C. (2014). Energy intensity, target level of energy intensity, and room for improvement in energy intensity: An application to the study of regions in the EU. Energy Policy. 67: 648-655.

[23] Kitani, O. (1999). Energy and biomass engineering, CIGR handbook of agricultural engineering. ASAE Publications, St Joseph, MI.

[24] Singh, G., Singh, S. & Singh, J. (2004).Optimization of energy inputs for wheat crop in Punjab. Energy Conversion Management. 45:453– 465.

[25] Ozkan, B., Akcaoz, H., & Fert, C. (2004). Energy input–output analysis in Turkish agriculture. Renewable Energy. 29(1): 39–51.

[26] Mohammadi, A. & Omid, M. (2010). Economical analysis and relation between energy inputs and yield of greenhouse cucumber production in Iran. Applied Energy. 87(1): 191-196.

[27] Renewable Energy and Energy Efficiency Organization. (2019). Ministry of Energy of the Islamic Republic of Iran. http://www.satba.gov.ir//

[28] Mousavi-Avval, S.H., Rafiee, S. & Mohammadi, A. (2011). Optimization of energy consumption and input costs for apple production in Iran using data envelopment analysis. Energy. 36: 2765-2772.

[29] Bames, A. (2006). Does multi-functionality affect technical efficiency? A non-parametric analysis of the Scottish dairy industry. Jornal of Environmental Management. 80(4): 287-294.

[30] Elhami, B., Shahvarooghi Farahani, S. & Marzban, A. (2019). Improvement of energy efficiency and environmental impacts of rainbow trout in Iran. Artificial Intelligence in Agriculture. 2:13–27.

[31] Baldini, E. Alberghina, O. Bargioni, G. Cobianchi, D. Iannini, B. Tribulato, E. & Zocca, A. (1982). Analisi energetiche di alcune colture arboree da frutto 34.Melo. Riv Ingegneria Agraria,13: 119-130.

[32] Akdemir, S., Akcaoz, H., Kizilari, H. (2012). An analysis of energy use and input costs for apple production in Turkey. Journal of Food, Agriculture & Environment. 10 (2): 473-479.

[33] Khoshnevisan, B., Rafiee, S., Omid, M. & Mousazadeh, H. (2013). Applying data envelopment analysis approach to improve energy efficiency and reduce GHG (greenhouse gas) emission of wheat production. Energy. 58: 588-593.

[34] Nabavi-Pelesaraei, A., Abdi, R., Rafiee, S. & Ghasemi Mobtaker, H. (2014) Optimization of energy required and greenhouse gas emissions analysis for orange producers using data envelopment analysis approach. Journal of Cleaner Production. 65: 311-317.

[35] Mohseni, P., Borghei, A. M. & Khanali, M. (2018). Coupled life cycle assessment and data envelopment analysis for mitigation of environmental impacts and enhancement of energy efficiency in grape production. Journal of Cleaner Production. 197: 937-947.