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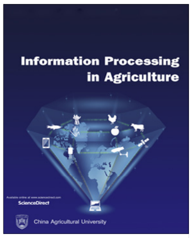

Optimization of energy consumption and environmental impacts of chickpea production using data envelopment analysis (DEA) and multi objective genetic algorithm (MOGA) approaches

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ABSTRACT

Energy consumption in agricultural products and its environmental damages has increased in recent centuries. Life cycle assessment (LCA) has been introduced as a suitable tool for evaluation environmental impacts related to a product over its life cycle.

In this study, optimization of energy consumption and environmental impacts of chickpea production was conducted using data envelopment analysis (DEA) and multi objective genetic algorithm (MOGA) techniques. Data were collected from 110 chickpea production enterprises using a face to face questionnaire in the cropping season of 2014–2015. The results of optimization revealed that, when applying MOGA, optimum energy requirement for chickpea production was significantly lower compared to application of DEA technique; so that, total energy requirement in optimum situation was found to be 31511.72 and 27570.61 MJ ha^{-1} by using DEA and MOGA techniques, respectively; showing a reduction by 5.11% and 17% relative to current situation of energy consumption. Optimization of environmental impacts by application of MOGA resulted in reduction of acidification potential (ACP), eutrophication potential (EUP), global warming potential (GWP), human toxicity potential (HTP) and terrestrial ecotoxicity potential (TEP) by 29%, 23%, 10%, 6% and 36%, respectively. MOGA was capable of reducing the energy consumption from machinery, farmyard manure (FYM) diesel fuel and nitrogen fertilizer (the mostly contributed inputs to the environmental emissions) by 59%, 28.5%, 24.58% and 11.24%, respectively. Overall, the MOGA technique showed a superior performance relative to DEA approach for optimizing energy inputs and reducing environmental impacts of chickpea production system.

Abbreviations: GHG, green house gas; LCA, life cycle assessment; DEA, data envelopment analysis; TE, technical efficiency; PTE, pure technical efficiency; SEF, scale efficiency; DMU, decision making unit; CRS, constant returns to scale; VRS, variable returns to scale; GA, genetic algorithm; EA, evolutionary algorithm; MOGA, multi objective genetic algorithm; VIF, variance inflation factor; FYM, farmyard manure; ME, machine energy; IE, irrigation energy; ER, energy ratio; EP, energy productivity; SE, specific energy; NEG, net energy gain; DE, direct energy; IDE, indirect energy; RE, renewable energy; RI, respiratory inorganics; NRE, non renewable energy; FU, functional unit; LCI, life cycle inventory; LCIA, life cycle impact assessment; ACP, acidification potential; EUP, eutrophication potential; GWP, global warming potential; HTP, human toxicity potential; TEP, terrestrial ecotoxicity potential

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1. Introduction

Chickpea (*Cicer arietinum L.*), commonly known as garbanzo, is a type of pulse with one seedpod containing two or three peas [1]. This herbage plant is usually grown in the summer and has atmospheric nitrogen-fixing root nodules [2].

There are two main varieties of chickpea including Kabuli and Desi; Kabuli variety has light color, large seeds and a smooth coat; while, Desi variety, with a rough coat, has smaller and darker seeds cultivated mostly in Ethiopia, Mexico and humid regions of Iran [1].

Based on the FAO statistics [3], Iran was the 7th largest producer of chickpea after India, Australia, Pakistan, Turkey, Myanmar and Ethiopia, respectively.

The average chickpea yield in Iran is 500 kg ha^{-1}; while the world average yield is 900 kg ha^{-1} [4]. Total production of chickpea crop in Iran was about 176,000 tons in 2011. The majority of Iranian chickpea, more than 30% is produced in Esfahan province [5].

In developing countries like Iran, agricultural mechanization is essential to support the economic growth and meet the food demand for growing population. Energy use efficiency in agriculture is one of the conditions for sustainable agricultural production, since it preserves fossil resources and decreases air pollution [6]. However, emissions from agriculture, shows a growing trend during the recent years due to a high application of synthetic nitrogen, direct energy inputs and intensive use of farm machinery in Iranian agriculture [7].

Agricultural greenhouse gas (GHG) emissions account for 10–12% of all manmade GHG emissions [8]. Assessing the impact at broader space and temporal scales is what life cycle assessment (LCA) does by considering the production and transport of inputs and the resulted emissions in a certain product or service system [9]. LCA has been applied more widely in agricultural and industrial fields [10–13]. For example, Iriarte et al. [14] explored LCA of sunflower and rapeseed production systems in Chile. They showed that rapeseed production had a higher environmental impact than sunflower growing in most impact categories. In another study in Italy, environmental performance of tomato, melon, pepper, cherry tomato, and zucchini production in different greenhouse typologies (tunnel and pavilion) were assessed. Their investigations showed that, the use of pavilions can allow the seasonal rotation of different types of cultivations, with sensible reduction of impacts [15].

Data envelopment analysis (DEA) is a mathematical model that is used extensively in many settings for measuring the efficiency and benchmarking of decision making units (DMUs) [16]. DEA is a data-driven frontier analysis technique that floats a piecewise linear surface to rest on top of the empirical observations, considered as efficient frontier [17]. In contrast to the parametric methods, DEA does not require a function to relate inputs and outputs [18]. Reig-Martínez and Picazo-Tadeo [19] reported that DEA was a useful tool to improve the productive efficiency of farms. Mohammadi et al. [20] investigated optimization of energy inputs for kiwifruit production in Golestan province of Iran. They found that total energy input could be saved by 12.17%. Also, optimization of energy use improved the energy use efficiency, specific energy (SE) and net energy gain (NEG) by 13.86%, 12.17% and 22.56%, respectively. Chauhan et al. [21] used DEA to assess the efficiencies of farmers with regard to energy use in rice farming in India. In this study, the technical efficiency (TE), pure technical efficiency (PTE) and scale efficiency (SEF) of farmers were estimated at 0.83, 0.92 and 0.77, respectively.

Genetic algorithm (GA) is a flexible scheduling and optimization technique based on the natural selection process [22]. It finds the problem solutions by using methods inspired by natural evolutions, such as inheritance, mutation, selection and crossover [23]. Much different from single-objective problem, it is complicated to minimize or maximize all objective functions concurrently when objective functions are in trade-off relationship. Nevertheless, many tribulations in agricultural and engineering domains are multi-objective optimization type [24]. A literature review demonstrates that, some researchers have reported the valuable application of multi-objective genetic algorithm (MOGA) in resource management of cropping systems [23,25,26]. In Italy, Cordeschi et al. [27] developed the optimal minimum-energy scheduler for the joint adaptive load balancing and provisioning of the computing-plus-communication resources. The average energy savings of the proposed scheduler over the static and hybrid ones may be larger than 60% and 25%, respectively, even when the peak-to-mean ratio (PMR) of the offered workload is less than two. Also, the corresponding average energy loss with respect to the corresponding sequential scheduler equipped with perfect knowledge of the future workload is typically limited up to 4–6%.

Khoshnevisan et al. [28] employed the MOGA technique to minimize global warming potential (GWP), respiratory inorganics (RI) and non-renewable energy use (NRE) of watermelon production. The results showed that a reduction of 27% in RI and 35% in GW and NRE can occur if an appropriate combination of resources is used in watermelon production. The difference between DEA and evolutionary algorithms (EA), such as MOGA, is that DEA approach not able to calculate global optimum values. In DEA approach the optimum values are obtained on the basis of units under consideration though in this method are not determined global optimum. In the other words, the sole purpose of the study in DEA is to select the DMU which consumed energy efficiently in comparison with all DMUs under consideration [23]. To consider different objectives in optimization techniques and find global optimum solutions, MOGA can be employed.

The sustainable production of chickpea in Iran requires the consideration of energy flow and environmental impacts in the production systems. However, to the best of knowledge of the authors, no previous analytical work has been reported on the energy consumption and environmental impacts of chickpea production in Iran.

Therefore, the general objectives of this study are as follows:

1. Calculation the energy indices (energy ratio, productivity energy, specific energy and net energy) for chickpea crop in the study region.
2. Estimation of some environmental impact (GWP, ACP, HTP, TEP and EUP) using life cycle assessment.
3. Determine efficient and inefficient units of energy consumption and their emissions by using DEA.
4. The using of MOGA to optimize energy consumption and environmental impacts.
5. Comparison DEA and MOGA models to optimize energy consumption and environmental impacts.
6. Presenting some Strategies in order to achieve sustainable agricultural with the lowest input consumption and lowest emissions level.

2. Materials and methods

2.1. *Study region and data collection*

The study was carried out in Esfahan province of Iran during 2014–2015 cropping season. Esfahan province has 6.5% of total area of the Iran and is located in the center of the country, within 30° 42′ and 34° 30′ north latitude and 49° 36′ and 55° 32′ east longitude. The required data was collected from 110 chickpea producers by using face to face survey method. The number of chickpea producers was calculated using Cochran method as follows [29]:

$$n = \frac{N \times S^2 \times t^2}{(N-1)d^2 + (S^2 \times t^2)} \tag{1}$$

In this formula, 'n' is the required sample size, 'N' is the number of all chickpea farms in target population, 'S' is the standard deviation in the pre-tested data, 't' is the t value at 95% confidence limit (1.96) and 'd' is the permissible error which was defined to be 5% for a confidence level of 95%.

2.2. *Energy analysis*

In this study, the inputs used for the chickpea production were seed amounts, human labor, electricity, irrigation, diesel fuel, machinery, chemicals, chemical fertilizers and farmyard manure (FYM); while output was chickpea yield, calculated per hectare. The energy associated with all inputs except for irrigation and machinery was estimated directly by multiplying the corresponding activity data by the appropriate energy equivalent (Table 1).

The energy of irrigation was calculated as follows [30]:

$$\mathrm{IE} = \frac{d \times g \times H \times Q}{\eta_1 \times \eta_2} \tag{2}$$

where 'IE' is irrigation energy (J $\mathrm{ha^{-1}}$), 'd' is the water density (1000 kg $\mathrm{m^{-3}}$), 'g' is the acceleration of gravity (9.81 m $\mathrm{s^{-2}}$), 'H' is the total dynamic head (m), 'Q' is the overall amount of water, including losses by evaporation, drainage run-off, etc. ($\mathrm{m^3\ ha^{-1}}$), 'η_1' is the pump efficiency and 'η_2' is the overall efficiency of the power device, electric or diesel.

The machinery energy was calculated as follows [30]:

$$\mathrm{ME} = \frac{G \times M_p \times t}{T} \tag{3}$$

Table 1 – Energy equivalent of inputs and output in chickpea production.

Input–output (unit)	Energy equivalent (MJ per unit)	References
1. *Inputs*		
Seed (kg)	14.7	[32,46]
Chemical fertilizer (kg)		
Nitrogen (N)	78.1	[32,46]
Phosphate (P_2O_5)	17.4	[30,32]
Potassium (K_2O)	13.7	[30,32]
FYM (kg)	0.3	[29]
Machinery (kg)		
Tractor	138	[30,32]
Plow	180	[32]
Disk	149	[32]
Boundaries	160	[32]
Leveler	149	[32]
Planter	133	[32]
Sprayer	129	[32]
Rotary Hoes	148	[32]
Thrashing (h)	62.7	[32]
Chemicals (kg)		
Herbicide	238	[44]
Insecticide	101.2	[44]
Fungicide	216	[58]
Diesel (L)	47.8	[44]
Labor (h)	1.96	[6,44]
Electricity (kWh)	11.93	[21,54]
2. *Output (kg)*		
Chickpea	14.7	[32,46]

where, 'ME' is the machinery energy (MJ $\mathrm{ha^{-1}}$), 'G' is mass of machine (kg), 'M_p' is energy equivalent of machinery (Table 1), 't' is the time that machine used per unit area (h $\mathrm{ha^{-1}}$) and 'T' is the economic life time of machine (h).

Therefore, the energy ratio (ER, energy use efficiency), energy productivity (EP), SE and NEG were calculated as follow [29,30].

$$\mathrm{ER} = \frac{\text{Output energy }(\mathrm{MJ\ ha^{-1}})}{\text{Input energy }(\mathrm{MJ\ ha^{-1}})} \tag{4}$$

$$\mathrm{EP} = \frac{\text{Chickpea output }(\mathrm{kg\ ha^{-1}})}{\text{Energy input }(\mathrm{MJ\ ha^{-1}})} \tag{5}$$

$$\mathrm{SE} = \frac{\text{Energy input }(\mathrm{MJ\ ha^{-1}})}{\text{Chickpea output }(\mathrm{kg\ ha^{-1}})} \tag{6}$$

$$\mathrm{NEG} = \text{Output energy }(\mathrm{MJ\ ha^{-1}}) - \text{Input energy }(\mathrm{MJ\ ha^{-1}}) \tag{7}$$

ER is computed by the ratio of input fossil fuel energy and output food energy; or in other words, shows the efficient use of energy in crop production. EP prepared quantitative data on how much yield is obtained per unit of the consumed energy. SE is a measure of the amount of input energy per unit of obtained product. NEG is specified as the difference between the energy expended to harvest an energy source and the amount of energy gained from that harvest.

For the growth and development of energy consumption in agriculture, it can be divided into direct energy (DE), indirect energy (IDE), renewable energy (RE) and NRE [31]. The DE covers human labor, diesel, electricity and water used in chickpea production; while IDE included energy embodied in seeds, chemical fertilizers, chemicals, FYM and machinery. The RE consists of human labor, seeds, FYM and water for irrigation and NRE includes diesel, electricity, chemicals, chemical fertilizers and machinery [32].

2.3. LCA analysis

LCA can be defined as a systematic inventory and analysis of the environmental impacts that are caused by a product or process starting from the extraction of raw materials, production, use, etc. (from cradle to grave). A LCA study is divided into four phases including, definition of the goal and scope, compiling an inventory of relevant inputs and outputs, evaluating the potential environmental impacts associated with inputs and outputs and interpreting the results of the inventory and impact phases in relation to the objectives of the study (Fig. 1) [33,34].

In an LCA, the goal and scope of the study is stating stage. The goal of the LCA in this study is the computation of some environmental impacts of chickpea production by consideration of agricultural proceedings, materials and energy inputs used during the crop production.

In LCA, the system boundary is a part of the scoping definition stage and it is a key factor that can affect the results of LCA studies [35]. The reactions between unit processes are not necessarily straight, but may also be affected by changes in the market mechanism, i.e. supply and demand, that connects the processes [15]. In this study, the farm gate was chosen as the system boundary and the environmental impacts were evaluated from inputs used that are entered to farm up to harvested chickpea crop (Fig. 2).

With application of LCA to agricultural processes, different functional units (FUs) can be selected. In many LCA studies of agricultural production systems, the FU is land-based (e.g., 1 ha) [26]. Nevertheless, the mass-based functional unit; e.g. 1 ton of crop produce; is prevalent in LCA studies of agricultural systems [36,37]. Thus, two functional units were chosen: mass-based (1 ton of produced chickpea) and land-based (per ha).

Life cycle inventory (LCI) considers the energy, resources consumption and emissions. The detailed quantitative data for chickpea production system upon which the analysis was based are summarized in Table 2.

Inventory data for the production of chemical fertilizers came from the EcoInvent®2.0 database [38]. Erickson et al. [39] indicated that 30% of N fertilizer leaches deeper down into the soil. In this study, insecticides, fungicides and herbicides were classified as a single category referred to as “pesticides”. The inventory data for pesticides was taken from the EcoInvent®2.0 database [38].

Based on the literature, it has been suggested that 30–50% of the total sprayed pesticides be accounted as emissions into the air [9]. Electrical pumps were the only use of electricity in chickpea production system in the studied area. It was assumed that, the source of electricity in power plants was natural gas. In chickpea production system, all farms applied diesel for agricultural machinery, especially by tractors and plows during farm operations. The emitted pollution for background data (exploration, refining and combustion of fossil fuels) was adapted from the literature [38].

The aim of life cycle impact assessment (LCIA) is interpretation of the LCI data. There are various methods globally for categorizing and characterizing the life cycle environmental impacts including factors of characterization, normalization, weighting and damaging [40].

In this study, we used characterization and weighting factors. A literature review revealed that CML2 baseline 2000 V2/-world developed by the Institute of Environmental Science of Leiden University is commonly used in LCA studies of agricultural production [41]. The present study considers five LCA impacts in the CML2 baseline 2000 V2.05/Netherlands, 1997/ characterization method that are shown in Table 3. Impact categories have been considered in this study, play the most

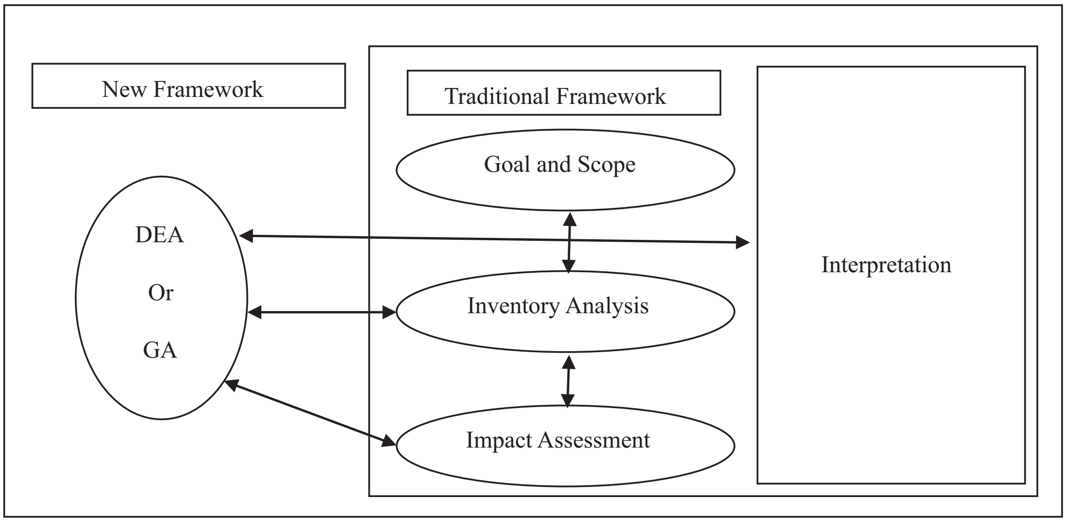

Fig. 1 – LCA framework with regard to DEA and GA Techniques. (indeed, inventory and impacts of LCA, Interpreted by DEA and GA) Adapted from Khoshnevisan et al. [28].

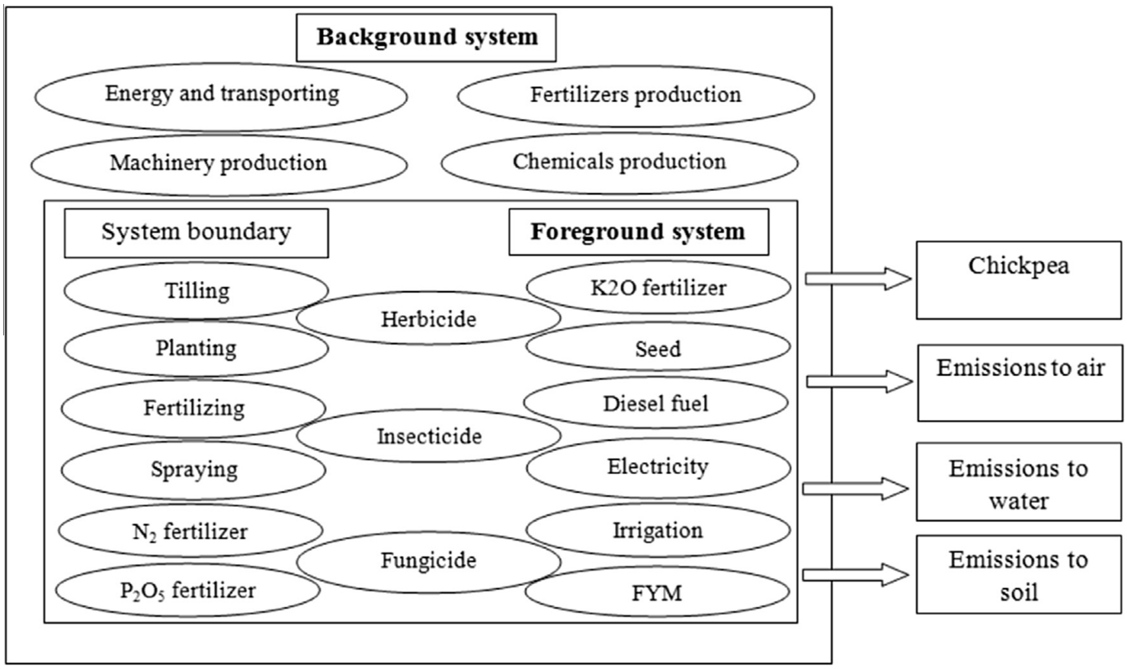

Fig. 2 – System boundaries and relevant inputs of the chickpea production system.

Table 2 – Life cycle inventory data for chickpea production.

Inputs	Unit	Average	Lower bound	Upper bound	Selection based on
Seed	kg	65.99	55	80	Minimum and maximum consumption in the region
Nitrogen (N)	kg	125.59	100	150	Minimum and maximum consumption in the region
Phosphate (P_2O_5)	kg	134.27	100	180	Minimum and maximum consumption in the region
Potassium (K_2O)	kg	81	50	100	Minimum and maximum consumption in the region
FYM	kg	1636.36	0	5000	Exporters' suggestions for the region
Herbicide	kg	1.37	0.86	2.17	Minimum and maximum consumption in the region
Insecticide	kg	1.91	0.66	3.00	Minimum and maximum consumption in the region
Fungicide	kg	3.14	1.87	5.00	Minimum and maximum consumption in the region
Machinery	kg	4433.91	2400	12,231	Farmers' experiences and degree of farm mechanization
Diesel fuel	L	118.10	73	174	Farmers' experiences and degree of farm mechanization
Labor	hr	201	245	170	Exporters' suggestions for the region
Water	m^3	289.27	250	320	Minimum and maximum consumption in the region
Electricity	kWh	568.22	500	650	Minimum and maximum consumption in the region

Table 3 – Environmental impacts affiliated with the production of chickpea.

Impact categories	Nomenclature	Measurement units	Equation	Reference
Acidification potential	ACP	kg SO_2 eq.	$\mathrm{ACP} = \sum_i \mathrm{AP}_i \times m_i$[a,b] (8)	[12]
Eutrophication potential	EUP	kg PO_4^{2-} eq.	$\mathrm{EUP} = \sum_i \mathrm{EP}_i \times m_i$[c] (9)	[12]
Global warming potential[d]	GWP	kg CO_2 eq.	$\mathrm{GWP} = \mathrm{GWP}_{\alpha,i} \times m_i$[e] (10)	[12]
Human toxicity potential[d]	HTP	kg 1,4-DCB eq.[e]	$\mathrm{HTP} = \sum_i \sum_{ecom} \mathrm{HTP}_{ecom,i} \times m_{ecom,i}$[g,h] (11)	[12]
Terrestrial ecotoxicity potential[d]	TEP	kg 1,4-DCB eq.[f]	$\mathrm{TEP} = \sum_i \sum_{ecom} \mathrm{TETP}_{ecom,i} \times m_{ecom,i}$[g] (12)	[12]

a AP_i = Acidification Potential for substance 'i' emitted to the air.
b m_i = The emission of substance 'i' to air, water or soil.
c EP_i = The EUP for substance 'i' emitted to air, water or oil.
d Considering 100 years.
e $GWP_{\alpha,i}$ = The GWP for substance 'i' integrated over ' α ' years (α = Considering 100 years).
f DCB = dichlorobenzene.
g $HTP_{ecom,i}$ and $TETP_{ecom,i}$ = The $HTP_{ecom,i}$ and $TETP_{ecom,i}$ (the characterization factor) for substance 'i' emitted to emission compartment 'ecom' (=air, fresh water, seawater, agricultural soil or industrial soil).
h $m_{ecom,i}$ = The emission of substance 'i' to medium 'ecom'.

pivotal role to carry out a LCA study. Emissions have been calculated and converted into the measurement units of each impact category (characterization factors). Some impact categories have been employed previously by other researches [14,15]. SimaPro V8.0 software was used to analyze the environmental profile of chickpea production.

2.4. *Selected DEA model*

DEA compares each producer with only the “best” producers. In the DEA literature, a producer is usually referred to as a DMU. An inefficient DMU can be made efficient either by decreasing the amount of inputs while retaining the output constant (input oriented); or symmetrically, by increasing the amount of output while holding the level of inputs constant (output oriented) [16]. In this study, input-oriented DEA seems more proper, given that it is more possibility to ratiocinate that in the agricultural segment a farmer has more control over inputs rather than output levels.

There are two kinds of DEA models included: CCR and BCC models. Charness et al. [42] expand CCR model based on constant returns to scale (CRS) and measure the TE of a DMU. On the other hand, Banker et al. [43] introduced the BCC model based on variable returns to scale (VRS) and has been developed to measure PTE.

TE is calculated as follows:

$$\text{Max } h_k = \frac{\sum_{r=1}^{s}(u_{rk}y_{rk})}{\sum_{i=1}^{m}(v_{ik}x_{ik})} \tag{13}$$

Subject to:

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

$$u_{rk}, y_{rk} \geqslant 0; \quad r = 1, \ldots, s; \quad i = 1, \ldots, m$$

where ‘k’ is the DMU being evaluated in the set of $j = 1, 2, \ldots, n$; ‘x’ is the amount of input; ‘y’ is the output produced; ‘m’ and ‘s’ represent the number of inputs and outputs respectively produced by the DMUs; and ‘u_{rk}’ and ‘v_{ik}’ are the matrix of weights assigned to outputs and inputs, respectively.

Also, the PTE can be estimated by a dual linear programming problem as follows [20]:

$$\text{Max } z = uy_j - u_j \tag{14}$$

Subject to:

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

$v \geqslant 0, \quad u \geqslant 0$ and u_0 is unconstrained in sign.

where ‘z’ and u_0 ’ are scalar and free in sign. ‘u’ and ‘v’ are output and input weight matrixes, and ‘Y’ and ‘X’ are corresponding output and input matrixes, respectively. The letters ‘x_i’ and ‘y_i’ refer to the inputs and output of jth DMU.

Therefore, SEF gives quantitative information of scale characteristics; it is the potential productivity gain from achieving optimal size of a DMU. SEF can be calculated by the relation between TE and PTE as below [44]:

$$\text{SEF} = \frac{\text{TE}}{\text{PTE}} \tag{15}$$

In the current case study, the DEA is used to identify the inefficient units of energy used. Also, combination of LCA and DEA methodology helps skippers and operators of these cultivation systems to be aware of their wasteful practices and of the need to reduce consumption levels in order to reduce environmental impacts.

Finally, in order to assess the efficiency indices of energy and environmental, basic information entered to Excel 2007 spreadsheets and then DEA software Efficiency Measurement Systems (EMS) V.1.3, was applied.

2.5. *Selected MOGA model*

GA is a search heuristic approach that used to generate useful solutions to optimization and search problems. GAs simulated the survival of the fittest among individuals over consecutive generation. Each generation consists of a population of character strings that are analogous to the chromosome. Each individual represents a point in a search space and a possible solution. The individuals in the population are then made to go through a process of evolution. At each step of this evolution, two members of the population were randomly chosen as parents, and children are considered as the next generation. After an initial population is randomly generated, the algorithm evolves the through five operators which inspired of nature [26]:

1. A population of chromosomes is produced.
2. The fitness is evaluated.
3. A loop is formed to generate new population.

The following are the steps must be repeated until population is completed:

(1) Selection,
(2) Crossover,
(3) Mutation,

and
(4) Accepting.

4. The new generating is used to run the algorithm.
5. Stopping criteria are evaluated.

To optimize the multi-objective function, we used from a branch of EAs, the MOGA. This method is useful in combination with LCA in order to minimize the environmental impacts of a product system.

The MOGA method starts with a clear definition of the objective functions. The five impacts categories including GWP, EUP, HTP, ACP and TEP, which need to be minimized; and chickpea yield, which should to be maximum, was selected as the objective functions. The objective functions can be generally defined as follows:

$$F_{max/min} = \sum_{i=1}^{j} C_i X_i + \alpha \tag{16}$$

where ‘$F_{max/min}$’ is the maximizing or minimizing objective function, ‘X_i’ is the input variables, ‘C_i’ states the model coefficients (regression coefficients) and ‘α’ is the constant coefficient of the model (Table 4).

Table 4 – The parameters and coefficients of objective functions.

Input	Parameters	Yield (β)	ACP (γ)	EUP (η)	GWP (δ)	HTP (λ)	TEP (ω)
Constant	α	1652.37	73.892	0.467	545.63	74.892	4.230
Seed	X_1	0.923	0.099	0.026	11.151	2.272	0.103
Nitrogen (N)	X_2	0.835	0.035	0.007	7.30	2.589	0.036
Phosphate (P_2O_5)	X_3	0.136	0.067	0.014	12.17	5.398	0.120
Potassium (K_2O)	X_4	0.382	−0.024	−0.004	−4.57	−2.500	−0.017
FYM	X_5	−0.003	0.011	0.003	1.318	0.384	0.012
Herbicide	X_6	31.88	−0.706	−0.148	−100.176	−45.900	−0.661
Insecticide	X_7	3.54	−1.309	−0.307	−156.007	−49.408	−1.354
Fungicide	X_8	8.65	−0.242	−0.061	−15.413	−1.850	−0.194
Machinery	X_9	−0.001	0.015	0.002	2.742	2.504	0.010
Diesel	X_{10}	1.37	0.021	0.005	1.881	0.187	0.024
Labor	X_{11}	0.272	−0.026	−0.007	−2.283	0.908	−0.036
Water	X_{12}	−0.153	−0.002	−0.0006	−0.190	−0.057	−0.002
Electricity	X_{13}	0.276	0.0005	0.0001	−0.035	−0.127	−0.001

To determine coefficients of the model, all data about energy inputs, crop yield and five LCA indices were entered into Excel 2007 spreadsheets and SPSS V. 20 software program. Another factor that must be considered is the variance inflation factor (VIF). If VIF for one of the variables is around or greater than 5, it needs to be excluded from the model [45].

The objective function of crop (F_1) developed for this study was to be maximum while five objective functions (ACP (F_2), EUP (F_3), GWP (F_4), HTP (F_5) and TEP (F_6)) were to be minimized. MATLAB V7.14 (R2012a) software was used to develop MOGA. This software finds the minimum of each objective function when it solves an optimization problem. Therefore, the first objective function should be multiplied by (−1) as follows:

$$F_1 = (-1) \times \alpha_{f(1)} + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 + \beta_9 X_9 + \beta_{10} X_{10} + \beta_{11} X_{11} + \beta_{12} X_{12} + \beta_{13} X_{13} \quad (17)$$

$$F_2 = \alpha_{f(2)} + \gamma_1 X_1 + \gamma_2 X_2 + \gamma_3 X_3 + \gamma_4 X_4 + \gamma_5 X_5 + \gamma_6 X_6 + \gamma_7 X_7 + \gamma_8 X_8 + \gamma_9 X_9 + \gamma_{10} X_{10} + \gamma_{11} X_{11} + \gamma_{12} X_{12} + \gamma_{13} X_{13} \quad (18)$$

$$F_3 = \alpha_{f(3)} + \eta_1 X_1 + \eta_2 X_2 + \eta_3 X_3 + \eta_3 X_3 + \eta_4 X_4 + \eta_5 X_5 + \eta_6 X_6 + \eta_7 X_7 + \eta_8 X_8 + \eta_9 X_9 + \eta_{10} X_{10} + \eta_{11} X_{11} + \eta_{12} X_{12} + \eta_{13} X_{13} \quad (19)$$

$$F_4 = \alpha_{f(4)} + \delta_1 X_1 + \delta_2 X_2 + \delta_3 X_3 + \delta_4 X_4 + \delta_5 X_5 + \delta_6 X_6 + \delta_7 X_7 + \delta_8 X_8 + \delta_9 X_9 + \delta_{10} X_{10} + \delta_{11} X_{11} + \delta_{12} X_{12} + \delta_{13} X_{13} \quad (20)$$

$$F_5 = \alpha_{f(5)} + \lambda_1 X_1 + \lambda_2 X_2 + \lambda_3 X_3 + \lambda_4 X_4 + \lambda_5 X_5 + \lambda_6 X_6 + \lambda_7 X_7 + \lambda_8 X_8 + \lambda_9 X_9 + \lambda_{10} X_{10} + \lambda_{11} X_{11} + \lambda_{12} X_{12} + \lambda_{13} X_{13} \quad (21)$$

$$F_6 = \alpha_{f(6)} + \omega_1 X_1 + \omega_2 X_2 + \omega_3 X_3 + \omega_4 X_4 + \omega_5 X_5 + \omega_6 X_6 + \omega_7 X_7 + \omega_8 X_8 + \omega_9 X_9 + \omega_{10} X_{10} + \omega_{11} X_{11} + \omega_{12} X_{12} + \omega_{13} X_{13} \quad (22)$$

Three forms of constraints that can be used in MOGA are given as below:

- Linear equality: i.e. $A \times X = B$.
- Linear inequality: i.e. $A \times X \leqslant B$.
- A set of upper (UB) and lower bounds (LB): i.e. $lb \leqslant X \leqslant ub$

Table 2 shows upper and lower bounds which considered to run the model.

MOGA is capable of searching logical solutions to a multi-objective problem; As a result, it can find a diverse set of solutions for difficult problems without being dominated by any other solution. This process is repeated until a termination condition has been reached. Common terminating conditions are as follows [23]:

1. A solution is found that satisfies minimum criteria.
2. A fixed number of generations is reached.
3. An allocated budget (computation time) was gotten.
4. The highest ranking solutions fitness is reaching or has reached a plateau such that successive iterations no longer produce better results.
5. Combinations of the above.

In this study, we applied terminating of number one.

3. Results and discussion

3.1. Energy use pattern in chickpea production

Table 5 displays how much energy from different sources was consumed for chickpea production in Esfahan province of Iran in the growing season of 2014–2015. The average of total energy input was estimated at 33211.18 MJ ha^{-1} while on average 33462.52 MJ ha^{-1} output energy was obtained. The results demonstrated that the most significant contributors to the total energy input were chemical fertilizers (13254.7 MJ ha^{-1}), electricity (6818.72 MJ ha^{-1}) and diesel fuel (5645.18 MJ ha^{-1}), respectively, where chemical fertilizers made up 29.35% of the total input energy followed by electricity (20.4%). N, P_2O_5 and K_2O respectively accounted for 74%, 18% and 8% of the total chemical fertilizers energy consumption. This is in agreement with the results of Salami and Ahmadi [46], who reported that, the budget of energy for chickpea production strongly depends on the rate of diesel fuel and nitrogen fertilizer. In contrast, Patil et al. [47] in India claimed that the greater shares of input energy were observed for human labor and bullock pair (28.53%), as majority of

Table 5 – Energy inputs and output for chickpea production in Esfahan, Iran.

Inputs/output	Average energy equivalent (MJ/ha)	Percentage of each value	SD
A. Inputs			
1. Seed	970.06	2.92	77.67
2. Chemical fertilizers			
a) Nitrogen	9808.65	29.53	889.42
b) Phosphorus (P_2O_5)	2336.34	7.03	314.86
c) Potassium (K_2O)	1109.70	3.34	228.37
3. Farmyard manure	490.90	1.47	707.04
4. Chemical			
a) Herbicide	328.30	0.98	76.91
b) Insecticide	193.50	0.58	51.42
c) Fungicide	678.68	2.04	158.85
5. Machinery	799.24	2.40	382.61
6. Diesel fuel	5645.18	16.99	1377.37
7. Human labor	473.64	1.42	26.14
8. Water for irrigation	3557.92	10.71	413.29
9. Electricity	6818.72	20.53	363.97
Total energy input	33211.18	100	4543.46
B. Output			
Total energy output	33462.52	100	1138.26

operations were done with this force. Following human labor and bullock pair, seed (25.78%), chemical fertilizer (22.28%) and pesticides (14.85%) were the main energy consuming inputs in their study. The cause of difference between mentioned study and our study was the using of women labor (11%) and bullock pair (10%) instead of machinery. Khoshnevisan et al. [48] reported that the average of energy consumption and total output energy in watermelon production was calculated as 53626.19 MJ ha^{-1} and 56895.50 MJ ha^{-1}, respectively. The energy used in irrigation system (61%), Plastic (14%) and N-based fertilizers (9%) were responsible for more than 80% of the total input energy input in this cultivation. Therefore, irrigation systems used in watermelon production should be upgraded and be replaced with modern ones. Drip irrigation systems can be used instead of flood irrigation systems.

Moreover, several studies have recently been performed on energy consumption of crop production in Iran, showing that fossil fuels and chemical fertilizers have the largest share in energy consumption [49–52].

Table 6 shows the energy indices of chickpea production in Esfahan province of Iran. Average chickpea yield was about 2276 kg ha^{-1}. The ER, EP, SE and NEG of chickpea production in Esfahan province were 1.02, 0.06 kg MJ^{-1}, 14.54 MJ kg^{-1} and 251.36 MJ ha^{-1}, respectively. The amount of ER indicated that output energy of chickpea was 1.02 times greater than total input energy. In another study led by Patil et al. [47] in India different results were obtained. They reported that ER and EP of chickpea production were calculated as 10.35 and 0.304 kg MJ^{-1}. Such a big difference was caused by lower energy consumption in Indian chickpea production. More specifically, lower use of chemical fertilizers was the main reason of such a big difference.

Other researchers reported the results of 0.02 for basil [7], 1.1 for watermelon [23] and 2.86 for barley production [29]. In addition, as can be seen in Table 6, the shares of DE, IDE, RE and NRE forms from total energy input calculated as 49.47%, 50.53%, 17.34% and 82.66%, respectively.

3.2. *LCA results*

The comprehensive results of five impact categories are shown in Figs. 3 and 4. The results well showed that the application of agricultural machinery, nitrogen fertilizers, diesel fuel and FYM played the key role in environmental consequences of chickpea production in the surveyed region.

Table 6 – Energy indices of chickpea production.

Items	Unit	Average	SD
Yield	kg ha^{-1}	2276.36	77.43
Energy ratio	–	1.02	0.1
Specific energy	MJ kg^{-1}	14.54	1.51
Energy productivity	kg MJ^{-1}	0.06	0.007
Net energy gain	MJ ha^{-1}	251.36	3461.99
Direct energy	MJ ha^{-1}	16495.77 (49.66%)	2064.73
Indirect energy	MJ ha^{-1}	16715.41 (50.33%)	2537.51
Renewable energy	MJ ha^{-1}	5492.83 (16.53%)	1131.57
Non-renewable energy	MJ ha^{-1}	27718.34 (83.46%)	3483.64

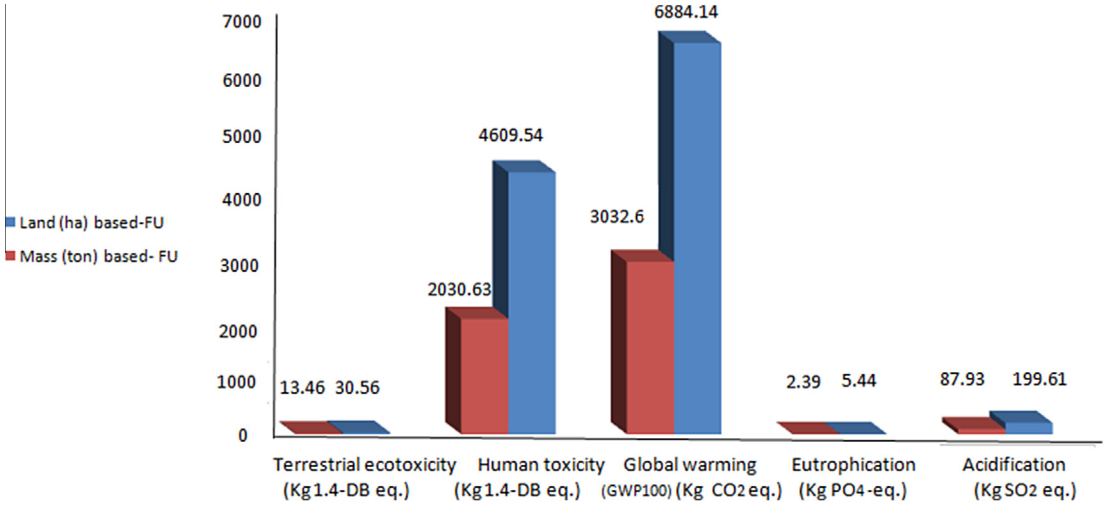

Fig. 3 – Life cycle impacts per two FUs.

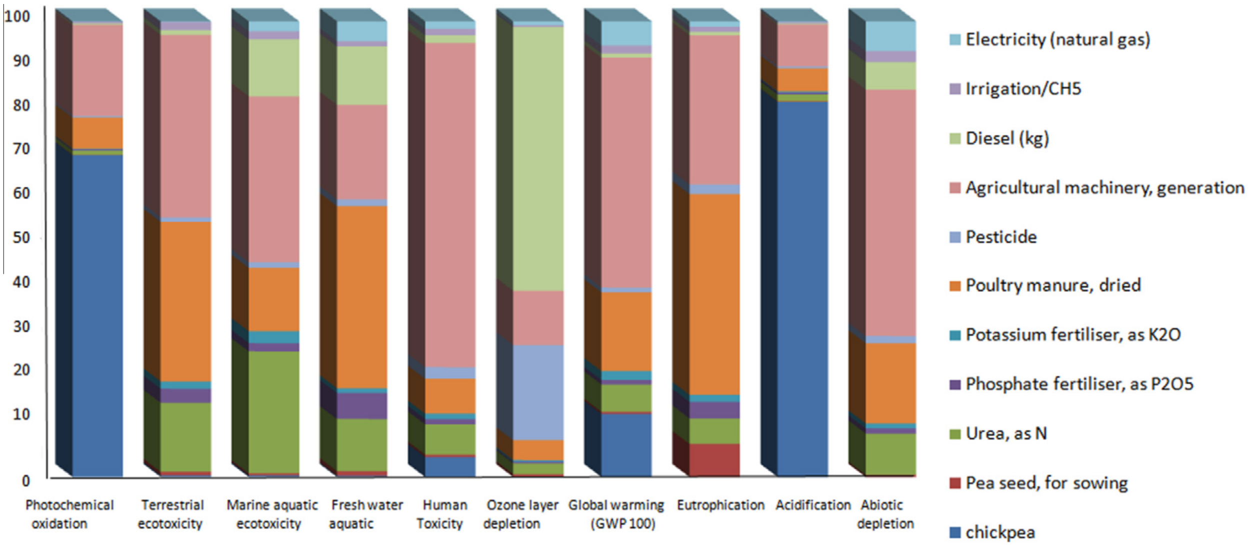

Fig. 4 – Contribution of inputs to environmental impact categories.

Based upon the obtained results, GWP was estimated at 3032.60 kg CO_2 eq. t^{-1}. Due to the lack of similar studies the results are compared with other agricultural crops to show the magnitude of indices estimated. In a study led by Iriarte et al. [14] in Chile, GWP for sunflower and rapeseed productions was estimated at 890 and 820 kg CO_2 eq. per t of crop. This high difference can be interpreted by large application of such agricultural inputs as machinery and chemical fertilizers (mainly N) in the production of chickpea. Considering EUP, emissions from FYM and agricultural machinery showed a pivotal role in causing EUP. Khoshnevisan et al. [53] concluded that in open field strawberry production, N-based fertilizers (0.17 kg PO_4^{3-} eq.) and energy used in traction (0.14 kg PO_4^{3-} eq.) had the greatest effect on EUP. Also in the impact category ACP, direct emissions from diesel fuel and chemical fertilizers ranked first among all input categories (Fig. 4).

Nemecek et al. [54] compared the environmental burdens of organic farming vs integrated production systems in Swiss. They showed that the N_2O and CO_2 emissions from chemical fertilizers made high contributions to GWP.

Iriarte et al. [14] in Chile concluded that, N-based fertilizers had the significant effects on the five impact categories of ACP, EUP, GWP, HTP and TEP in sunflower and rapeseed productions. Similarly, Khoshnevisan et al. [35] claimed that the electricity was the largest contributor to the total emissions caused by greenhouse cucumber production in Iran. Fig. 5 shows the emission of pollutants to the air, water and soil. These emissions were calculated as weighting unit in term of mPt. Here, Pt is an abbreviation of Point which is the unit of the weighting results with 1000 Pt the total environmental impact of one (average) European citizen during one year [55]. With respect to the obtained results (Fig. 5),

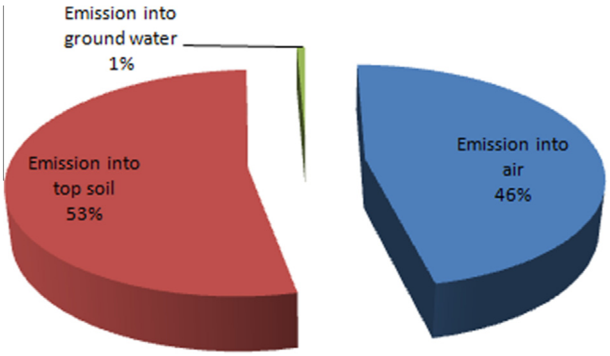

Fig. 5 – Share of emissions for 1 ton of chickpea production, in Iran.

the shares of total emissions for 1 ton of chickpea production consist of 210.39 mPt (46%) emissions into air, 235.74 mPt (53%) emission into top soil and 76.54 (1%) emissions into ground water.

3.3. *DEA results*

The outcomes of BCC and CCR models showed that 99 (90%) and 39 (35.45%) chickpea farmers out of 110 farmers who participated in our study were recognized as the technically and pure technically efficient (score of 1), respectively (Fig. 6). It indicated substantial inefficiency in use of agricultural inputs in chickpea production.

It is worth mentioning that, there is not variation between soil texture or soil yield potential efficiency and efficiency of farmers; because information have been obtained from the neighboring town ship, with the same geographical location, same rainfall, the same temperature and same vegetation cover. Also in this study, farm size did not have significant differences on efficiency of farmers. Mousavi-Avval et al. [44] reported that, from the total of 94 farmers considered in soybean production, 40 farmers (42.55%) had the PTE score of 1. Moreover, from the PTE farmers 26 farmers (27.66%) had the technical efficiency score of 1. It was due to their disadvantageous conditions of scale size.

On the other hand, from relatively inefficient farmers, 11 and 40 farmers had PTE and TE in the 0.9–1 range, respectively. Moreover, 31 DMUs obtained the efficiency score of less than 0.9, which are known as inefficient producers.

Based on the obtained results from the models (Eqs. (11), (12) and (13)), the average values of PTE, TE and SEF were calculated as 0.998, 0.944 and 0.945, respectively (Fig. 7). The results showed that, about 6% of total energy inputs could be saved without reducing the chickpea yield. Nassiri and Singh [56] applied DEA to determine efficient and inefficient of farmers in paddy production in Punjab; they reported that in zone 2, TE, PTE and SEF were at 0.88, 0.91 and 0.96, respectively. Their results showed that, about 12% of total energy inputs could be saved without reducing the paddy yield.

The inputs–output energy balance of efficient and inefficient farmers (based on the CCR model) is shown in Table 7. The results revealed that, the efficient farmers applied less inputs than inefficient farmers, except for FYM. Also the main differences between efficient and inefficient farmers were found to be for application of potassium, insecticide and machinery. Nevertheless, the production yield for efficient farmers was found to be 1.35% lesser than that of inefficient ones. Among the investigated environmental impacts, for the EUP, GWP and HTP, there is no significant difference between efficient and inefficient farmers; while, the emissions of ACP and HTP for efficient farmers were higher than that of inefficient farmers.

3.4. *MOGA results*

MOGA is capable of finding optimal solutions. Fig. 8(D) has plotted the Pareto front for the first two objective functions (EUP and yield) showing that MOGA has been converged.

MOGA numerated 99 optimal solutions by which crop yield was maximized and the five impact categories were minimized. It should be noted that the following filters were considered to select the final results;

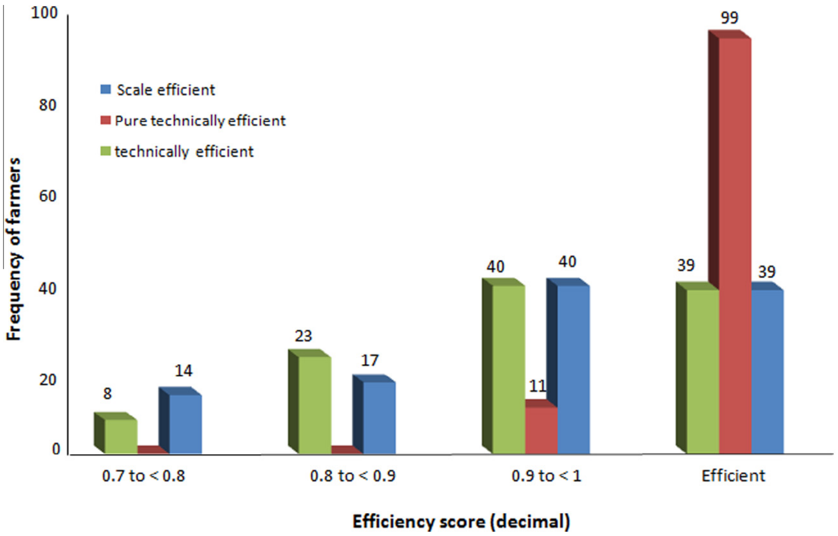

Fig. 6 – Efficiency score distribution of chickpea producers.

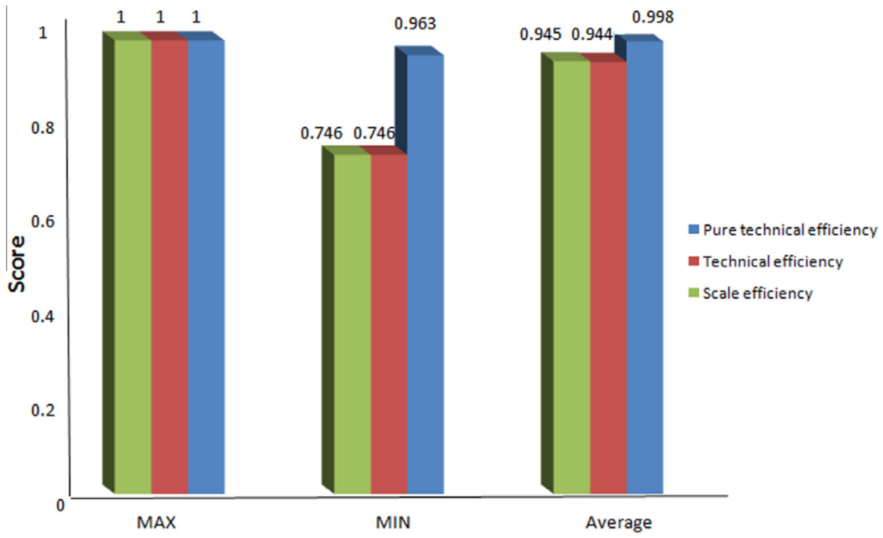

Fig. 7 – Efficiency indices of chickpea production.

Table 7 – Comparison of efficient and inefficient farmers in chickpea production.

Item (Unit)	Efficient farmers (Unit ha^{-1}) (A)	Inefficient farmers (Unit ha^{-1}) (B)	Difference (%) (B - A) × 100/B
A. Inputs			
1. Seed (kg)	942.30	985.31	4.36
2. Chemical fertilizers (kg)			
a) Nitrogen (N)	9502.16	9977.00	4.75
b) Phosphorus (P_2O5)	2244.15	2386.98	5.98
c) Potassium (K_2O)	1009.93	1164.50	13.27
3. Farmyard manure (kg)	500.00	485.91	−2.89
4. Chemicals (kg)			
a) Herbicide	313.08	336.66	7.00
b) Insecticide	177.31	202.40	12.39
c) Fungicide	647.30	695.91	6.98
5. Machinery (kg)	739.27	834.13	11.37
6. Diesel fuel (L)	5357.27	5803.32	7.68
7. Human labor (h)	463.36	479.75	3.41
8. Water for irrigation (m^3)	3415.12	3636.36	6.08
9. Electricity (kWh)	6461.53	6900.00	6.35
B. Outputs			
1. Chickpea (Kg)	2256.41	2287.32	1.35
2. ACP (kg SO_2 eq.)	90.45	89.25	−1.34
3. EUP (kg PO_4^{2-} eq.)	2.95	3.11	5.14
4. GWP (kg CO_2 eq.)	2997.14	3120.88	3.96
5. HTP (kg 1,4-DCB eq.)	2012.17	2003.91	−0.41
6. TEP (kg 1,4-DCB eq.)	13.32	13.64	2.34

1. The total inputs calculated from optimum solutions should be less than the average of the region.
2. The crop yield calculated from optimum solutions should be lower than the maximum value in the region.
3. The total environmental indices should be less than that of in the current condition. Therefore, from 99 solutions obtained by MOGA, 29 optimum solutions were selected as tabulated in Table 8. Among these solutions the one optimum solution was determined by selecting the largest values in each input. Thus the final optimum solution of the inputs can be found in Table 8 as shown in bold type. The results revealed that each of five environmental indices studied, can be reduced significantly while the crop yield has been increased. Accordingly, in all optimum conditions, the emissions of ACP, GWP, EUP and TEP are not only less than the average but also lower than the minimum emissions observed in the studied area. For example, GWP and HTP, for one ton of chickpea, decreased from 3032.60 kg CO_2 and 2030.63 kg 1.4-DCB to 2750.40 kg CO_2 and 11920.60 kg 1.4-DCB, respectively. Also, based on the calculated solution in Table 8, the total inputs used in region can be reduced, that among them, machinery, human labor, fungicide and FYM have the greatest reduction with 59%, 50%, 32% and 29%, respectively.

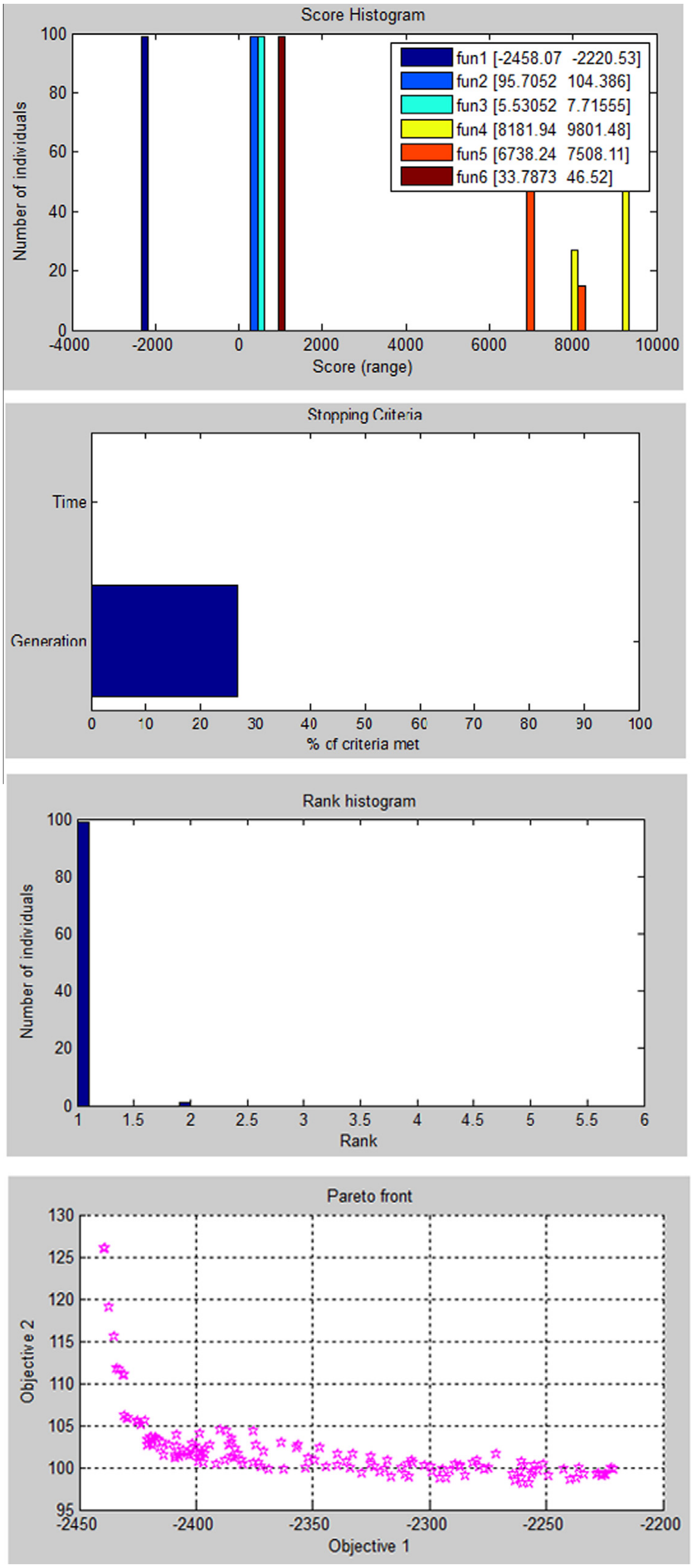

Fig. 8 – Termination criteria of MOGA for finding optimum solutions.

Table 8 – The selected results of solutions produced by MOGA (the final optimum values of inputs are shown in bold type).

Seed	N	P_2O_5	K_2O	FYM	Herbicide	Insecticide	Fungicide	Machinery	Diesel	Labor	Water	Electricity	Yield	ACP	EUP	GWP	HTP	TEP
55.67	111.47	104.57	78.29	1176.20	1.02	1.69	2.37	2924.40	89.1	232.6	**286.1**	503.78	2442.54	60.46	1.44	2054.27	1398.84	4.97
55.86	111.68	105.12	78.76	1183.46	1.10	1.62	2.12	2924.20	89.0	232.1	281.7	504.17	2283.90	59.99	1.35	2405.09	1441.51	4.73
55.85	120.58	105.80	79.89	1190.56	1.11	1.55	3.06	2982.10	105.4	237.9	280.6	559.53	2434.07	60.39	1.55	2470.51	1569.83	5.48
55.86	115.77	106.04	77.58	1194.51	1.11	1.76	3.07	2984.60	114.2	238.7	28.63	558.54	2435.44	59.25	1.47	2314.04	1445.26	4.08
56.58	112.86	104.83	74.40	1171.29	1.12	1.79	2.41	2925.50	94.3	234.6	270.8	535.35	2435.97	60.13	1.61	2444.99	1582.27	5.42
56.83	118.39	107.29	79.86	1178.61	1.17	1.79	3.08	3198.70	116.8	239.3	270.9	554.07	2432.67	59.46	1.50	2343.25	1492.34	4.48
56.58	114.24	107.36	79.89	1200.75	1.19	1.79	3.05	3013.90	116.4	234.6	268.6	532.02	2417.09	61.20	1.73	2578.40	1756.03	6.88
56.09	113.11	113.56	77.57	1188.52	1.12	1.77	2.60	2958.50	103.3	236.7	279.1	554.32	2395.65	60.98	**1.85**	2546.09	1702.33	6.58
56.60	111.72	**115.24**	74.40	1187.08	1.15	1.77	2.40	2961.60	95.3	237.0	2.88	536.68	2440.51	60.24	1.52	2432.13	1423.03	4.87
55.86	122.56	105.25	79.86	1186.26	1.20	1.79	2.2	**3296.80**	89.0	232.1	272.4	504.30	2442.38	62.50	1.57	**2750.40**	1906.45	8.70
56.09	114.65	106.95	79.89	1179.80	**1.25**	1.78	3.06	2978.50	114.4	**240.6**	273.0	563.58	2437.91	59.69	1.38	2370.85	1529.01	4.79
56.03	113.11	110.83	79.47	1174.77	1.23	1.77	2.61	2957.90	113.9	238.7	273.7	564.54	2276.17	59.42	1.54	2336.88	1481.71	4.39
55.98	112.86	107.31	79.78	1182.12	1.16	1.77	3.07	3000.00	113.6	237.8	271.6	550.19	2203.14	59.56	1.78	2360.39	1492.42	4.56
57.26	117.44	107.77	80.33	1179.05	1.11	1.79	**3.13**	2925.10	108.1	237.7	273.3	550.02	2193.90	61.20	1.66	2329.83	1464.69	4.25
55.69	118.93	104.68	77.37	1182.13	1.11	1.75	2.38	3025.60	91.2	234.7	277.7	508.96	2197.35	60.98	1.75	2430.78	1661.18	5.72
56.79	112.34	106.56	79.69	1178.69	1.11	1.77	3.08	2948.40	115.9	236.0	277.0	559.01	2405.04	60.24	1.49	2488.69	1631.38	5.89
56.23	117.86	107.14	79.29	1198.87	1.10	1.78	2.73	2966.40	93.5	235.5	270.3	545.38	2214.50	**62.50**	1.51	2392.03	1541.18	5.00
56.58	114.23	105.76	72.42	1192.32	1.01	1.79	3.08	3025.60	108.5	234.6	272.1	535.30	2437.68	59.69	1.41	2530.31	1718.60	6.56
56.20	113.26	114.21	78.00	1186.97	1.05	1.77	2.40	2957.80	115.7	235.3	273.6	527.60	2208.74	59.42	1.63	2643.04	1787.96	7.65
56.62	112.70	107.15	79.56	1197.74	1.06	1.79	3.07	2966.43	101.4	237.9	278.7	557.02	2414.91	59.56	1.76	2516.45	1660.46	6.27
55.94	111.81	104.98	74.72	1197.75	1.11	1.79	2.19	2957.20	89.1	232.3	282.9	518.27	2437.39	59.38	1.62	2721.24	1846.61	8.13
58.57	116.29	105.09	79.91	1198.54	1.11	1.77	2.18	3110.80	112.0	239.0	279.5	560.95	2283.71	60.19	1.59	2347.98	1513.32	4.63
55.86	113.39	106.06	80.18	1187.06	1.05	1.78	3.07	2924.50	109.1	237.8	285.7	556.66	2336.17	60.56	1.40	2598.54	1744.01	7.20
56.30	**123.56**	107.30	**80.37**	**1201.85**	1.03	**1.79**	3.09	3108.60	**116.9**	236.9	271.0	**565.33**	**2444.88**	59.75	1.44	2740.02	**1920.60**	**8.71**
56.14	118.99	105.76	80.18	1196.05	1.03	1.77	2.90	2989.50	96.83	235.6	280.7	563.20	2279.32	60.85	1.72	2455.11	1560.41	5.43
56.58	113.11	105.46	72.94	1190.14	1.03	1.79	2.62	2921.10	102.7	234.6	269.4	535.34	2425.90	61.46	1.57	2695.35	1825.20	8.08
55.99	118.43	109.21	78.77	1198.52	1.01	1.77	3.04	2986.80	105.2	238.9	284.6	564.88	2398.39	60.70	1.49	2557.47	1637.76	6.20
56.42	112.59	104.82	79.66	1196.09	1.05	1.77	2.39	2925.40	104.9	234.6	270.0	522.98	2298.74	62.14	1.41	2682.69	1807.76	7.83
56.25	119.07	108.10	79.80	1198.41	1.06	1.76	3.09	3099.40	114.9	239.3	280.1	562.97	2436.79	59.50	1.47	2415.54	1411.90	4.74

Finally, despite higher consumption of inputs, crop yield is estimated at 2444.88 kg ha^{-1}, which is equal to the region's maximum under current condition. Applying new agricultural machineries and tractors with higher field capacity and using better approach in seedbed preparation (like reduced tillage systems) and in sowing operations instead of conventional methods, are highly recommended as practical solutions for decreasing energy consumption and negative environmental burdens caused by excessive use of different sources of energy in chickpea production in the studied area.

Also, the models offered by Shamshirband et al. [23] indicated that inputs of P_2O_5, N, K_2O and machinery can potentially be reduced by 58%, 54%, 45% and 40% in watermelon production. As presented in Table 8, all of the applied agricultural inputs were fully efficient where in reality it is not possible that a system treats totally efficiently but it can be a good help for farmers to find feasible ways for the reduction of agricultural inputs. When a system is optimized, it is likely that do not optimized all inputs but we can to combine different application of inputs in a way that all objective functions are met simultaneously [23].

3.5. *Comparison of DEA and GA for energy inputs*

In order to optimize the best combination of inputs, the lowest energy input is dedicated to the optimal combination was selected. As can be seen in Table 9, the total input energy for chickpea will be equal to 27,570 MJ ha^{-1} (17% of energy saving).

On the other hand, the outcomes of DEA showed that the total energy input can be decreased to the value of 31,511 MJ ha^{-1} (5.10% energy saving). It means that, GA was superior to DEA for finding optimal patterns of energy usage and reducing environmental impacts. The interesting point that is clear in this table, is the inability of DEA in optimization of FYM; So that, the amount of the input energy in the optimal value is higher than the actual value (-1.85% of energy saving). But unlike the DEA, GA was able to save FYM energy by 29%. Shamshirband et al. [23] employed the MOGA technique to minimize GHG emissions and maximize output energy of watermelon production. The results revealed that on average, 28% of the total energy input and 33% of the total GHG emissions in watermelon production can be reduced. On the other hand, optimization results with DEA, will decrease the consumption of energy inputs to 31,511 MJ ha^{-1} (5.10% of energy saving). In another study by Pahlavan et al. [57] in Iran, by optimization of energy consumption in rose production with DEA approach, on an average, about 43.59% of the total input energy could be saved without reducing the rose yield.

4. Conclusions

In this study, the ability of DEA and MOGA techniques was investigated in optimization of energy consumption and environmental impacts of chickpea production in Esfahan province of Iran. Summary of conclusions can be stated as follow:

- Total energy inputs and output for chickpea production were 33211.18 and 33462.52 MJ ha^{-1}, respectively. The energy input of chemical fertilizer (39.90%), mainly nitrogen, had the greatest share within the total energy inputs followed by electricity (20.53%). Accordingly, ER, EP, SE and NEG in chickpea production were 1.02, 0.06 kg MJ^{-1}, 14.54 MJ kg^{-1} and 251.36 MJ ha^{-1}, respectively.
- The LCA study showed that the most significant impact categories are ACP, EUP, GWP, HTP and TEP which they are related to the use of agricultural machinery for seedbed preparation and sowing operations, followed by the diesel fuel consumed, chemical fertilizers and FYM in the studied region. Therefore it expected that, using No-till and reduced tillage system, clean fuels such as biodiesel and bio-ethanol instead of fossil fuels and more efficient fertilizers application by Integrated Nutrient Management, not

Table 9 – The actual and optimal amounts of energy inputs in chickpea production system.

Inputs	Average actual energy (MJ ha^{-1})	Average optimal energy (MJ ha^{-1})	
		(DEA)	(GA)
1. Seed	970.06	942.30	818.34
2. Chemical fertilizers			
a) Nitrogen	9808.65	9502.16	8705.70
b) Phosphorus (P_2O_5)	2336.34	2244.15	1819.51
c) Potassium (K_2O)	1109.70	1009.93	992.15
3. FYM	490.90	500	351.38
4. Chemical			
a) Herbicide	328.30	313.08	240.38
b) Insecticide	193.50	177.31	156.86
c) Fungicide	678.68	647.30	457.92
5. Machinery	799.24	739.27	326.01
6. Diesel fuel	5645.18	5357.27	4257.54
7. Human labor	473.64	463.36	232.14
8. Water for irrigation	3557.92	3415.12	2680.63
9. Electricity	6818.72	6461.53	6045.36
Total energy input	33211.18	31511.72	27570.61

only for reducing negative effects to environment, human health, maintaining sustainability, but also for providing higher energy use efficiency.

- Based on the results of DEA, the average values of PTE, TE and SEF were calculated as 0.998, 0.944 and 0.945, respectively. Also, potassium fertilizer, insecticide and machinery energy inputs had the highest potential for saving energy; so, if inefficient farmers followed efficient farmers, they would significantly improve their ER.
- In order to optimize the energy crop yield and studied environmental impacts by MOGA, of all agricultural inputs, machinery held the first rank with a reduction of 59%. It shows that machinery management technique in this cultivation is not efficient at all. On the other hand, the values of environmental impacts of ACP, EUP, GWP, HTP and TEP using MOGA, reduced up to 29%, 23%, 10%, 6% and 36%, respectively.
- In the optimum condition, total energy inputs for chickpea production achieved to 5.11% of saving energy using DEA. However, about 17% of total energy inputs could be saved without reducing the chickpea yield through GA.
- From the results obtained, it is concluded that there is a great potential for reducing energy consumption and environmental impacts in the chickpea production and optimization by MOGA was significantly better than the optimization by DEA approach.

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REFERENCES

[1] Lopez R, Vaca M, Terres H, Lizardi A, Morales J, Flores J, et al. Kinetics modeling of the drying of chickpea (Ci cer Arietinum) with solar energy. Energy Procedia 2014;57:1447–54.
[2] Babaoglu M. Chickpea and agriculture. Edirne: Trakya Agricultural Research Institute Publication; 2003.
[3] Food and Agriculture Organization of the United Nations (FAO). Livestock's long shadow-environmental issues and options. Food and Agriculture Organization of the United Nations; 2008.
[4] Soltani A, Hajjarpour A, Vadez V. Analysis of chickpea yield gap and water-limited potential yield in Iran. Field Crops Res 2016;185:21–30.
[5] MAJ. Annual agricultural statistics. Ministry of Jihad-e-Agriculture of Iran, <www.maj.ir>; 2013.
[6] Beheshti Tabar I, Keyhani A, Rafiee S. Energy balance in Iran's agronomy (1990–2006). Renewable Sustainable Energy Rev. 2010;14:849–55.
[7] Pahlavan R, Omid M, Akram A. Energy input-output analysis and application of artificial neural networks for predicting greenhouse basil production. Energy 2012;37:171–6.
[8] Brown LR, Flavin CF, French H. State of the world. New York: W.W. Norton; 1998. p. 251.
[9] Sahle A, Potting J. Environmental life cycle assessment of Ethiopian rose cultivation. Sci Total Environ 2013;443:163–72.
[10] Andersson K, Ohlsson T, Olsson P. Screening life cycle assessment (LCA) of tomato ketchup: a case Study in Sweden. J Cleaner Prod 1998;6:277–88.
[11] Mohammadi A, Rafiee S, Jafari A, Dalgaard T, Knudsen MT, Keyhani A, et al. Potential greenhouse gas emission reductions in soybean farming: a combined use of life cycle assessment and data envelopment analysis. J Cleaner Prod 2013;54:89–100.
[12] Khoshnevisan B, Rafiee S, Omid M, Mousazadeh H, Sefeedpari P. Prognostication of environmental indices in potato production using artificial neural networks. J Cleaner Prod 2013;52:402–9.
[13] Lee D-H. Development and environmental impact of hydrogen supply chain in Japan: assessment by the CGE-LCA method in Japan with a discussion of the importance of biohydrogen. Int J Hydrogen Energy 2014;39:19294–310.
[14] Iriarte A, Rieradevall J, Gabarrell X. Life cycle assessment of sunflower and rapeseed as energy crops under Chilean conditions. J Cleaner Prod 2010;18:336–45.
[15] Cellura M, Longo S, Mistretta M. Life cycle assessment (LCA) of protected crops: an Italian case study. J Cleaner Prod 2012;28:56–62.
[16] Zhou P, Ang BW, Poh KL. A survey of data envelopment analysis in energy and environmental studies. Eur J Oper Res 2008;189(1):1–18.
[17] Adler N, Friedman L, Sinuany-Stern Z. Review of ranking methods in the data envelopment analysis context. Eur J Oper Res 2002;140(2):249–65.
[18] Seiford LM, Thrall RM. Recent developments in DEA: the mathematical programming approach to frontier analysis. J Econometrics 1990;46:7–38.
[19] Reig-Martínez E, Picazo-Tadeo AJ. Analysing farming systems with data envelopment analysis: citrus farming in Spain. Agric Syst 2004;82:17–30.
[20] Mohammadi A, Rafiee S, Mohtasebi S, Mousavi Avval SH, Rafiee H. Energy efficiency improvement and input cost saving in kiwifruit production using data envelopment analysis approach. Renewable Energy 2011;36:2573–9.
[21] Chauhan NS, Mohapatra PKJ, Pandey KP. Improving energy productivity in paddy production through benchmarking – an application of data envelopment analysis. Energy Convers Manage 2006;47:1063–85.
[22] Janakiraman N, Nirmal Kumar P. Multi-objective module partitioning design for dynamic and partial reconfigurable system-on-chip using genetic algorithm. J Syst Archit 2014;60:119–39.
[23] Shamshirband S, Khoshnevisan B, Yousefi M, Bolandnazar E, Anuar NB, Abdol Wahab AW, Rehman Khan SU. A multi-objective evolutionary algorithm for energy management of agricultural systems – a case study in Iran. Renewable Sustainable Energy Rev 2015;44:457–65.
[24] Deb M, Banerjee R, Majumder A, Sastry GRK. Multi objective optimization of performance parameters of a single cylinder diesel engine with hydrogen as a dual fuel using pareto-based genetic algorithm. Int J Hydrogen Energy 2014;39:8063–77.
[25] Komly CE, Azzaro-Pantel C, Hubert A, Pibouleau L, Archambault V. Multi objective waste management optimization strategy coupling life cycle assessment and genetic algorithms: application to PET bottles. Resour Conserv Recycl 2012;69:66–81.
[26] Su M, Chen C, Zhifeng Y. Urban energy structure optimization at the sector scale: considering environmental impact based on life cycle assessment. J Cleaner Prod 2016;112:1464–74.
[27] Cordeschi N, Shojafar M, Amendola D, Baccarelli E. Energy-efficient adaptive networked datacenters for the QoS support of real-time applications. J Supercomput 2015;71(2):448–78.

[28] Khoshnevisan B, Bolandnazar E, Shamshirband S, Motamed Shariati H, Anuar NB, Mat Kiah MY. Decreasing environmental impacts of cropping systems using life cycle assessment (LCA) and multi-objective genetic algorithm. J Cleaner Prod 2015;86:67–77.
[29] Ghasemi Mobtaker H, Keyhani A, Mohammadi A, Rafiee S, Akram A. Sensitivity analysis of energy inputs for barley production in Hamedan Province of Iran. Agric Ecosyst Environ 2010;137:367–72.
[30] Pishgar-Komleh SH, Keyhani A, Mostofi-Sarkari MR, Jafari A. Energy and economic analysis of different seed corn harvesting systems in Iran. Energy 2012;43:469–76.
[31] Ozkan B, Kurklu A, Akcaz H. An Input-output energy analysis in greenhouse vegetable production: a case study for Antalya region of Turkey. Biomass Bioenergy 2004;26:189–95.
[32] Kitani O. Energy and biomass engineering. In: CIGR handbook of agricultural engineering. St. Joseph, MI: ASAE; 1999. p. 330.
[33] McDougall F, White P, Franke M, Hindle P. Life cycle assessment in integrated solid waste management: a life cycle inventory. Malden of USA: Blackwell Science Publishing; 2001. p. 103–28.
[34] International Organisation for Standardisation (ISO). Environmental management-life cycle assessment: requirements and guidelines (ISO 14044). Brussels; 2006.
[35] Khoshnevisan B, Rafiee S, Omid M, Mousazadeh H, Clark S. Environmental impact assessment of tomato and cucumber cultivation in greenhouses using life cycle assessment and adaptive neuro-fuzzy inference system. J Cleaner Prod 2014;73:183–92.
[36] Romero-Gámez M, Audsley E, Suárez-Rey E. Life cycle assessment of cultivating lettuce and escarole in Spain. J Cleaner Prod 2015;73:193–203.
[37] Keyes S, Tyedmers P, Beazley K. Evaluating the environmental impacts of conventional and organic apple production in Nova Scotia, Canada, through life cycle assessment. J Cleaner Prod 2015;104:40–51.
[38] Ecoinvent Center. Ecoinvent 2.0 database. Swiss centre for life cycle inventories, Dübendorf. <http://www.ecoinvent.ch>; 2007.
[39] Erickson JE, Cisar JL, Volin JC, Snyder GH. Comparing nitrogen run off and leaching between alternative residential landscapes. Crop Sci 2011;41:1889–95.
[40] Ecoinvent Center. Ecoinvent 2.0 database. Swiss centre for Implementation of life cycle impact assessment methods. <http://www.ecoinvent.ch>; 2010. p. 1–2.
[41] Anonymous. PRé Consultants. SimaPro 5 database manual; 2003.
[42] Charnes A, Cooper WW, Rhodes E. Measuring the efficiency of decision making units. Euro J Oper Res 1978;2:429–44.
[43] Banker R, Charnes A, Cooper W. Some models for estimating technical and scale inefficiencies in data envelopment analysis. Manage Sci 1984;30:1078–92.
[44] Mousavi-Avval SH, Rafiee S, Jafari A, Mohammadi A. Optimization of energy consumption for soybean production using data envelopment analysis (DEA) approach. Appl Energy 2011;88(11):3765–72.
[45] Tabatabaie SMH, Rafiee S, Keyhani A, Heidari MD. Energy use pattern and sensitivity analysis of energy inputs and input costs for pear production in Iran. Renewable Energy 2013;51:7–12.
[46] Salami P, Ahmadi H. Energy inputs and outputs in a chickpea production system in Kurdestan. Iran Afr Crop Sci J 2010;18:51–7.
[47] Patil SL, Mishra PK, Loganandhan N, Ramesha MN, Math SKN. Energy, economics, and water use efficiency of chickpea (*Cicer arietinum* L.) cultivars in Vertisols of semi-arid tropics, India 2014;Curr. Sci. 107:656–64.
[48] Khoshnevisan B, Bolandnazar E, Barak S, Shamshirband S, Maghsoudlou H, Torki A, Abdullah G. A clustering model based on an evolutionary algorithm for better energy use in crop production. Stoch Environ Res Risk Assess 2015;29 (8):1921–35.
[49] Banaeian N, Omid M, Ahmadi H. Energy and economic analysis of greenhouse strawberry production in Tehran province of Iran. Energy Convers Manage 2011;52:1020–5.
[50] Heidari MD, Omid M. Energy use patterns and econometric models of major greenhouse vegetable productions in Iran. Energy 2011;36:220–5.
[51] Mohammadi A, Tabatabaeefar A, Shahin S, Rafiee S, Keyhani A. Energy use and economical analysis of potato production in Iran a case study: Ardabil province. Energy Convers Manage 2008;49:3566–70.
[52] Mohammadi A, Omid M. Economical analysis and relation between energy inputs and yield of greenhouse cucumber production in Iran. Appl Energy 2010;87:191–6.
[53] Khoshnevisan B, Rafiee S, Mousazadeh H. Environmental impact assessment of open field and greenhouse strawberry production. Eur J Agron 2013;50:29–37.
[54] Nemecek T, Huguenin-Elie O, Dubois D, Gaillard G, Schaller B, Chervet A. Life cycle assessment of Swiss farming systems: I. Integrated and organic farming. Agr Syst 2011;104:233–45.
[55] Mousazadeh H, Keyhani A, Mobli H, Bardi U, Lombardi G, el Asmar T. Environmental assessment of RAMseS multipurpose electric vehicle compared to a conventional combustion engine vehicle. J Clean Prod 2009;17:781–90.
[56] Nassiri SM, Singh S. Study on energy use efficiency for paddy crop using data envelopment analysis (DEA) technique. Appl Energy 2009;86(1320):1325.
[57] Pahlavan R, Omid M, Rafiee S, Mousavi-Avval SH. Optimization of energy consumption for rose production in Iran. Energy Sustainable Develop 2012;16:236–41.
[58] Zangeneh M, Omid M, Akram A. A comparative study on energy use and cost analysis of potato production under different farming technologies in Hamadan province of Iran. Energy 2010;35:2927–33.