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ENERGY REQUIREMENT OPTIMIZATION OF GREENHOUSE VEGETABLE PRODUCTION USING DATA ENVELOPMENT ANALYSIS (DEA) METHOD IN ALGERIA

Ahmed NOURANI^{1*}, Abdelaali BENCHEIKH²

¹Scientific and Technical Research Center on Arid Regions (CRSTRA), Biskra, Algeria

²University of Ahmed Draia Adrar, Algeria

Algeria has recently experienced an important agricultural development in terms of gardening in plastic greenhouses thanks to the favourable factors (climatic conditions, etc.). In order to optimize the energy requirements, data from 29 farmers were collected, who qualitatively represent the greenhouse vegetable producers from the most productive sub-provinces of Biskra region (south of Algeria). Considering the various parametric and non-parametric methods for energy consumption optimization, data envelopment analysis is the most common non-parametric method applied. Results showed that the mean radial technical efficiency assumptions of the samples under constant returns to scale and variable returns to scale models were 0.88 and 0.98, respectively. The 51.72% of decision-making units were efficient on the basis of the constant returns to scale model; 79.31% decision-making units were observed efficient on the basis of variable returns to scale model. Calculation of optimal energy requirements for vegetable greenhouse indicated that 108.50 GJ·ha⁻¹ can be saved on machinery (1.38 GJ·ha⁻¹); diesel fuel (4.68 GJ·ha⁻¹); infrastructure (9.35 GJ·ha⁻¹); fertilizers (17.08 GJ·ha⁻¹); farmyard manure (12.05 GJ·ha⁻¹); pesticides (3.93 GJ·ha⁻¹); and electricity (60.03 GJ·ha⁻¹).

Keywords: greenhouse cultivation; input–output analysis; Biskra; DEA; Algeria

During the last twenty years, Algeria showed a significant agricultural development caused by prosperous gardening in plastic greenhouses thanks to the favourable climatic conditions and the governmental policy (Nourani and Bencheikh, 2017). As results of this development, Biskra province became the most significant producer of early vegetables nationally (Allache et al., 2015); the area occupied by the greenhouses increased by 528.52% over the last 20 years (Belhadi et al., 2016). Greenhouses are constructed for the purpose of achieving the controlled environment suitable for crop production (Akpenpuun and Mijinyawa, 2018).

Agriculture is both a producer and consumer of energy (Bahrami et al., 2011). It utilizes large amounts of locally available non-commercial energies, such as seeds, manure, etc., as well as commercial energies in form of diesel fuel; electricity; fertilizers; irrigation water; etc. (Kizilaslan, 2009). Efficient exploitation of energies allows the achievement of increments in production and productivity and contributes to the economy, profitability and competitiveness of agriculture sustainability in rural living (Singh et al., 2002). Multiple authors have dealt with energy consumption optimization in greenhouses, e.g. for vegetable production (Firoozi et al., 2014), for cucumber production (Banaeian et al., 2012); however, there has not been published a study on energy input–output efficiency optimization of greenhouse vegetable production in MENA region. Furthermore, no papers published took into

account that infrastructure can be a considerable input in energy analyses.

With these observations in mind, this study is focused on the determination of the energy use efficiency, wasteful use of energy and selected energy requirements for greenhouse vegetable production in Biskra province, in the south of Algeria, in order to optimize the energy consumption.

Material and methods

Survey

According to Rekibi (2015), Biskra province is responsible for more than 32% of national production of protected crops, making it the most significant producer of early vegetables in Algeria. Therefore, this study was conducted in this region specifically for this reason. It took place in Biskra province during the 2014–2015 season and employed face-to-face personal interviews via questionnaires consisting of sections aimed at the economic characteristics, practices, and farm management. There were 29 farmers – qualitatively representing the producers of greenhouse vegetables in the most productive sub-provinces of Biskra – who participated in interviews. The most frequently produced vegetables in these sub-provinces include tomatoes; cucumbers; eggplants; and pepper.

Contact address: Ahmed Nourani, Scientific and Technical Research Center on Arid Regions (CRSTRA), Biskra, Algeria
e-mail: nourani83@gmail.com

Energy pattern

Agricultural energy requirements can be divided into two groups: direct (human labour; diesel fuel; water for irrigation; etc.) and indirect (seeds; fertilizers; farmyard manure; chemicals; machinery; infrastructure; etc.). On the basis of the energy equivalents of inputs and outputs (Table 1), metabolisable energy was calculated.

In order to analyse the energy flow, energy ratio (*energy use efficiency, ER*); *net energy (NE)*; *energy productivity (EP)*; and specific energy indices were calculated as follows:

$$\text{output} - \text{input ratio (ER)} = \frac{\text{energy output (MJ} \cdot \text{ha}^{-1})}{\text{energy input (MJ} \cdot \text{ha}^{-1})} \quad (1)$$

$$\text{energy productivity (EP)} = \frac{\text{total output (kg} \cdot \text{ha}^{-1})}{\text{energy input (MJ} \cdot \text{ha}^{-1})} \quad (2)$$

$$\text{net energy (NE)} = \text{energy output (MJ} \cdot \text{ha}^{-1}) - \text{energy input (MJ} \cdot \text{ha}^{-1}) \quad (3)$$

$$\text{specific energy} = \frac{\text{energy input (MJ} \cdot \text{ha}^{-1})}{\text{vegetable output (kg} \cdot \text{ha}^{-1})} \quad (4)$$

Table 1 Energy equivalents of inputs and outputs in greenhouse vegetable production

Energy source	Unit	Energy equivalent (Mj·unit ⁻¹)	Reference
Inputs			
Human labour	h	1.96	Singh et al. (2002)
Machinery	h	62.7	Singh et al. (2002)
Diesel fuel	l	45.4	Bojacá et al. (2012)
Infrastructure			
– Steel	kg	33	Medina et al. (2006)
– Polyethylene		9.9	Medina et al. (2006)
– Synthetic fibre		1.2	Medina et al. (2006)
– PVC		11.6	Medina et al. (2006)
Fertilizers			
– N	kg	60.6	Ozkan et al. (2004)
– P ₂ O ₅		11.1	Ozkan et al. (2004)
– K ₂ O		6.7	Ozkan et al. (2004)
Farmyard manure	kg	0.3	Bojacá et al. (2012)
Pesticides			
– Fungicides	kg	216	Mohammadi and Omid (2010)
– Insecticides		101.2	Mohammadi and Omid (2010)
Plant materials			
– Plantlets	unit	0.2	Bojacá et al. (2012)
Water for irrigation	m ³	0.63	Bojacá et al. (2012)
Electricity	kW·h ⁻¹	3.6	Ozkan et al. (2004)
Output			
Tomato, cucumber, eggplant, pepper	kg	0.8	Ozkan et al. (2004)

Data envelopment analysis (DEA)

In terms of the various parametric and non-parametric methods for the energy consumption optimization, DEA is the most common method applied. Since its introduction, the DEA method has shown an exponential success: Emrouznejad et al. (2008) identified more than 4,000 published research articles on the DEA method in scientific journals or reference books. According to Huguenin (2013), this method was developed in order to evaluate the efficiency of a US federal program of resource allocation to schools ("Program Follow Through").

The DEA method makes it possible to evaluate the performance of the organizations (i.e. decision-making units – DMUs) that transform resources (inputs) into benefits (outputs). Its detailed description can be found in Banaeian et al. (2012).

Two basic models are utilized in DEA, each leading to the identification of a different efficiency frontier. The first model assumes that organizations evolve in a situation of constant returns to scale (CRS). According to this model, it is appropriate for all organizations to reach their optimal size (Charnes et al., 1978). The second model assumes that organizations evolve in a situation of variable returns to scale (VRS). In terms of this model, it is appropriate when organizations do not operate at their optimal size (Banker et al., 1984).

In order to select the inputs for DEA approach, a linear regression analysis for determination of effective energy inputs on yield was performed. The function used was of Cobb-Douglas production function form expressed as follows (Singh et al., 2004; Hatirli et al., 2006; Mohammadi and Omid, 2010; Banaeian et al., 2012):

$$Y_i = \alpha_0 + \sum_{j=1}^7 \alpha_j (x_{ij}) + e_i; \quad i = 1, 2, 3 \dots 29 \quad (5)$$

where:

Y_i – i_{th} greenhouse yield

x_{ij} – vector of energy inputs used in the production process (x_{i1} – human labour, x_{i2} – machinery, x_{i3} – diesel fuel, x_{i4} – infrastructure, x_{i5} – fertilizer, x_{i6} – pesticide, x_{i7} – farmyard manure, x_{i8} – plantlets, x_{i9} – water for irrigation, x_{i10} – electricity)

α_0 – constant term

α_j – coefficient of energy inputs which are estimated from the model

This function and its variations have been used by multiple authors (Singh et al., 2004; Hatirli et al., 2006; Mohammadi and Omid, 2010; Banaeian et al., 2012) to examine the relationship between input energy and yield.

In this study, input-oriented DEA seems more appropriate, given that it is more reasonable to argue that a farmer has more control over inputs rather than outputs in the agricultural sector (Nabavi-Pelesaraei et al., 2014).

Technical efficiency (TE)

Technical efficiency is a global measure of a DMU performance. The TE can be defined as follows (Nabavi-Pelesaraei et al., 2014):

$$TE_j = \frac{u_1 y_{1j} + u_2 y_{2j} \dots u_n y_{nj}}{v_1 x_{1j} + v_2 x_{2j} \dots v_m x_{mj}} = \frac{\sum_{r=1}^n u_r y_{rj}}{\sum_{s=1}^m v_s x_{sj}} \quad (6)$$

where:

u_r – weight given to output n

y_r – amount of output n

v_s – weight given to input n

x_s – amount of input n

r – number of outputs ($r = 1, 2, \dots, n$)

s – number of inputs ($s = 1, 2, \dots, m$)

j – j^{th} of DMUs ($j = 1, 2, \dots, k$)

To solve the Eq. 1, following linear programming (LP) was formulated:

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

$$\text{Subjected to } \sum_{r=1}^n u_r y_{rj} - \sum_{s=1}^m v_s x_{sj} \leq 0$$

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

$$u_r \geq 0, v_s \geq 0, \wedge \quad (7)$$

where:

θ – technical efficiency

Model (3) is known as the input-oriented CRS DEA model – it assumes constant returns to scale (CRS) (Nabavi-Pelesaraei et al., 2014).

Scale efficiency (SE)

The SE relates to the most efficient scale of operations in the sense of maximizing the average productivity (Firoozi et al., 2014). Furthermore, scale efficiency represents the potential productivity gain from achieving the optimal size of a DMU (Reyhani-Farashah et al., 2013). The relationship between technical and pure technical efficiency scores can be described by the next formula (Mousavi-Avval et al., 2011):

$$\text{scale efficiency} = \frac{\text{technical efficiency}}{\text{pure technical efficiency}} \quad (8)$$

Considering the analysis of efficient and inefficient DMUs, the energy-saving target ratio (ESTR) index can be used, which represents the inefficiency level for each DMU with respect to the energy consumption (Nourani and Bencheikh, 2017). The formula for it is as follows (Firoozi et al., 2014):

$$ESTR_j = \frac{\text{energy saving target}_j}{\text{actual energy input}_j} \quad (9)$$

The aim is to save energy by overall reduction in inputs without decreasing the outputs (j – j^{th} DMU).

The majority of calculation was performed by means of the free application Win4Deap 2, version 2.1.

Results and discussion

Data were collected from 29 protected vegetable producers in Biskra province. The average size of a local greenhouse is approx. 2.1 ha with a range from 0.25 up to 12.75 ha. Observed greenhouses were made of plastic and had metallic structure. Furthermore, the data showed that majority of greenhouses utilized drip irrigation and approx. 73% of farms were privately owned and 27% rented.

The survey was actually conducted with a higher number of farmers – 65 – since there are two essential drawbacks of deterministic frontier models: both non-parametric and parametric models are very sensitive to outliers and extreme values; and noisy data is not allowed (Pahlavan et al., 2011). Therefore, higher number of farmers was selected in order to assure homogeneity on the basis of a specific area character.

By means of Eq. 1, $R^2 = 0.92$ was given by regression analysis of performance. All significant inputs, such as human labour; plantlets; etc., were taken into account; and analysis adopted the significant inputs and assumed seven input variables: infrastructure; fertilizers; farmyard

Table 2 Statics description of adopted inputs and output (Mj·ha⁻¹)

	Machinery	Diesel fuel	Infrastructure	Fertilizers	Farmyard manure	Pesticide	Electricity	Yield
Max.	3,762	36,178.12	341,728.22	252,036	27,720	101,020.73	281,842.10	200,000
Min.	627	425.62	7,801.08	1,873.52	2,700	1,386	1,043.85	50,000
Mean	1,729.65	5,107.5	22,008.94	26,990.68	13,379.58	12,164.44	84,654.37	113,724.13
SD	742.39	7,414.62	61,502.86	46,145.70	6,725.31	20,590.45	70,952.94	36,756.82

manure; electricity; diesel fuel; pesticides; and machinery energy, which represent major energy inputs having impact on vegetable yield in the studied greenhouses, with 91% of total energy used. These are given in Table 2 with descriptive statistics for 29 vegetable producers. According to Cooper et al. (2001), the number of DMUs should be at least three times the total number of input and output factors taken into account when using the DEA model (Banaeian et al., 2012); therefore, this study works with a number of greenhouses that is three times the number of selected eight input-output variables for the performance model.

Technical, pure technical and scale efficiency of greenhouses

Table 3 describes the results acquired by means of input-oriented DEA. The mean radial TE of the samples under CRS and VRS assumptions were 0.88 and 0.98, respectively. Moreover, 51.72% of DMUs (15 units) were observed efficient on the basis of CRS model; whereas, on the basis of VCR model, score of the pure TE was shown by 79.31% of DMUs (23 units). This implies that, in average, vegetable greenhouses can reduce their inputs by 12% (2%) and still maintain the identical output level – increasing of the greenhouse TE actually results in lower input usage,

Table 3 Results of the technical efficiency scores (technical, pure, and scale) and returns to scale

DMU	Machinery	Diesel fuel	Infrastructure	Fertilizers	Farmyard manure	Pesticides	Electricity	Technical efficiency		Scale efficiency	RTS
								CRS	VRS		
1	1,254	11,350	10,441.916	75,340.40	18,168	12,459.360	14,092.105	1	1	1	
2	3,030.5	36,178.125	9,556.495	63,917.96	16,818	18,556.128	2,947.368	1	1	1	
3	2,508	14,896.875	10,289.178	9,968.16	4,800	1,764.720	10,736.842	1	1	1	
4	1,254	2,270	9,854.416	1,873.52	13,650	2,891.928	58,717.105	1	1	1	
5	1,463	851.25	12,727.083	16,576.72	8,400	6,128.760	93,947.368	0.825	1	0.825	IRS
6	1,463	16,315.625	10,246.330	33,302.32	8,550	11,760.30	10,892.449	0.918	1	0.918	IRS
7	1,254	1,418.75	10,292.416	26,807.72	22,230	5,969.250	156,578.95	0.726	0.924	0.786	IRS
8	3,135	5,675	10,596.916	10,747.68	16,800	3,841.354	36,013.158	1	1	1	
9	1,045	7,093.75	10,512.416	15,587.32	11,076	2,500.050	125,263.16	0.964	1	0.964	IRS
10	627	2,128.125	11,211.083	13,345.80	6,816	1,386.000	50,105.263	1	1	1	
11	1,881	2,128.125	11,040.416	13,320.64	8,400	2,023.152	156,578.94	1	1	1	
12	3,762	7,803.125	10,424.416	19,341.92	22,800	10,602.576	10,248.804	0.83	0.941	0.882	IRS
13	2,821.5	8,512.5	9,085.083	11,212.08	14,820	3,973.050	1,043.860	1	1	1	
14	1,881	9,931.25	10,300.988	3,403.76	22,230	5,996.160	10,736.842	1	1	1	
15	2,090	2,837.5	341,728.221	252,036.00	2,700	4,272.000	54,802.632	0.639	1	0.639	IRS
16	1,881	1,702.5	7,801.083	12,439.20	15,270	11,579.814	78,289.474	0.82	1	0.82	IRS
17	1,672	1,418.75	10,160.416	27,224.08	4,200	3,966.480	187,894.73	1	1	1	
18	1,672	1,418.75	10,820.416	26,136.52	4,200	3,257.280	75,157.895	1	1	1	
19	1,463	2,837.5	10,906.416	5,535.44	16,800	101,020.73	281,842.10	0.453	0.878	0.516	IRS
20	1,254	1,702.5	11,455.750	4,346.96	8,550	2,516.580	67,850.877	1	1	1	
21	1,985.5	1,418.75	10,112.416	18,032.00	2,940	14,253.278	56,368.421	0.591	1	0.591	IRS
22	1,881	709.375	11,432.416	20,359.00	22,230	46,751.400	250,526.31	0.67	0.854	0.785	IRS
23	1,254	993.125	10,678.131	18,431.40	17,100	1,729.740	89,473.684	1	1	1	
24	627	425.625	13,082.416	14,296.72	27,720	2,460.530	93,947.368	1	1	1	
25	1,567.5	993.125	13,012.988	9,481.60	18,900	48,045.600	89,473.684	0.663	0.989	0.670	IRS
26	1,881	1,276.875	10,575.528	5,912.74	9,810	7,297.476	93,947.368	0.808	1	0.808	IRS
27	1,254	851.25	12,164.416	13,343.20	15,750	4,879.392	125,263.16	0.668	0.99	0.675	IRS
28	731.5	2,270	9,875.166	21,634.64	12,600	2,632.320	46,973.684	1	1	1	
29	1,567.5	709.375	7,874.416	18,774.40	13,680	8,253.600	125,263.16	0.838	1	0.838	IRS

Fig. 1 Efficiency score distribution

production costs and higher profits, which is a motivation for producers to adopt new methods and technology (Firoozi et al., 2014).

Employing the Eq. 8, it is obvious that the scale efficiency equals to 1 for the units that had a score equal to 1 in CRS and VRS models. The efficiency score distribution of VRS and CRS models is shown in Fig. 1. Clearly, these results suggest that the difference between efficient and inefficient farmers was caused by differences in consumption of inputs in vegetable greenhouse production.

Consequently, farmers should adopt the consumption model of the efficient farmers. As shown in Fig. 1, 7 units were in the range 0.8–1 on the basis of CRS model, while VRS model results indicate that 6 units were equal to unity.

According to the results obtained, the DMUs designated with numbers 1, 2, 3, 4, 8, 10, 11, 13, 14, 17, 18, 20, 23, 24 and 28 are efficient and apply good practices. Due to same reason, CRS applied and scale efficiency equals to one, indicating that these farms are functioning at the most productive

scale size. The last table column – return to scale (RTS) – shows that all efficient DMUs (on the basis of TE) are functioning at constant return to scale (CRS), whereas the inefficient units are functioning at increasing return to scale (IRS), suggesting that there is need for significant adjustments in terms of yield and/or agricultural management. The IRS indicates that an increase in output was achieved by an increase in input resources, which was higher than proportionate. The scale efficiency (SE) reached the value of 0.88 in average, indicating that with efficient input utilization, the inefficient farmers can save some energy from the various input sources without any changes in agricultural practices. There were no units functioning at decreasing return to scale (DRS). Nabavi-Pelesaraei et al. (2016) investigated the wheat production energy efficiency with similar results.

Energy savings from different energy inputs

Table 4 illustrates the optimal energy requirements and energy savings in greenhouse vegetable production on the basis of the CRS model. In addition to this, a contribution to the savings in energy is also provided.

As shown in Table 4, the calculations of the optimal energy

Table 4 Optimal energy requirements and energy savings for vegetable greenhouse production

Input	Optimal energy requirement (MJ·ha ⁻¹)	Saving energy (MJ·ha ⁻¹)	Saving energy (%)	Contribution to the savings in energy (%)
Machinery	1,379.93	349.73	20.22%	1.27%
Diesel fuel	4,680.45	427.05	8.36%	4.31%
Infrastructure	9,348.70	12,660.24	57.52%	8.62%
Fertilizers	17,080.71	9,909.98	36.72%	15.74%
Farmyard manure	12,050.57	1,329.02	9.93%	11.11%
Pesticides	3,931.96	8,232.49	67.68%	3.62%
Electricity	60,033.21	24,621.16	29.08%	55.33%
Total energy	108,505.53	57,529.66	34.65%	100.00%

Table 5 Improvement of energy indices for vegetable greenhouse production

Indices	Unit	Actual quantity	Optimal quantity	Difference (%)
Energy ration	–	49%	72%	31.94
Energy productivity	kg·MJ ⁻¹	0.618162046	0.89941929	31.46
Net energy	MJ·ha ⁻¹	-92,992.09115	-35,462.42738	61.86
Specific energy	MJ·kg ⁻¹	1.6176988	1.1118285	31.67

requirements for vegetable greenhouse production suggest that 108.50 GJ·ha⁻¹ in total can be saved in terms of machinery (1.38 GJ·ha⁻¹); diesel fuel (4.68 GJ·ha⁻¹); infrastructure (9.35 GJ·ha⁻¹); fertilizers (17.08 GJ·ha⁻¹); farmyard manure (12.05 GJ·ha⁻¹); pesticides (3.93 GJ·ha⁻¹) and electricity (60.03 GJ·ha⁻¹). Consequently approx. 35% of total input energy in average can be saved if the farmers follow the recommendations provided in this study and maintain the current output level of greenhouse vegetable yield. Utilizing the similar methods, Firoozi et al. (2014) reported that, on average, 26.82% of the total input energy employed in greenhouse cucumber production in Iran can be saved.

Improvements of energy indices

Table 5 recapitulates the energy indices of actual and optimal quantities. The calculation demonstrates that the energy use efficiency is equal to 1.61 and 1.11 for actual and optimal quantities, respectively, with 0.51 of difference leading to an improvement of 31.67%. Furthermore, by converting the current energy use index to target energy use index, the energy ration, energy productivity and net energy can be improved approx. by 31.94%, 31.46%, 19.82% and 19.80%, respectively.

Nabavi-Pelesaraei et al. (2014) reported that the percentage of difference between target and optimal was approx. 24% for rice production.

Conclusions

This work is focused on optimization of the energy input-output for the protected crop production in Biskra province (South of Algeria) by means of the DEA approach. For this reason, a survey with 29 farmers was conducted.

Analysis adopted the significant inputs and assumed seven input variables: infrastructure; fertilizers; farmyard manure; electricity; diesel fuel; pesticides; and machinery energy – representing 91% of total energy used, as well as major energy inputs having significant impact on vegetable yield in the studied greenhouses.

The total energy necessary for protected crop production is 183.17 GJ per hectare. The 51.72% of DMUs (15 units) was observed efficient on the basis of CRS model; the pure technical efficiency score equalled to 1 in terms of 79.31% of DMUs (23 units) on the basis of VRS model, indicating their efficiency.

The calculation demonstrates that the energy use efficiency is equal to 1.61 and 1.11 for actual and optimal units, respectively, with 0.51 of difference leading to an improvement of 31.67%.

As recommendations, the following propositions can enhance the control over energy flow in protected vegetable production, as well as to allow the farmers to improve their financial situation; namely, providing farmers with training by a qualified person focused on improvement in their agricultural practices and enhancement of management over their inputs. Farmers should also improve the integrated pest management (IPM) by adoption of new methods for dealing with pests. In addition to these, awareness sessions for farmers regarding the effects of greenhouse gases on future generation should be elaborated.

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