Energy Use Pattern and Optimization of Energy Consumption for Greenhouse Cucumber Production in Iran Using Data Envelopment Analysis (DEA)

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Received: Semptember 22, 2011 Accepted: October 10, 2011 Published: December 1, 2011
doi:10.5539/mas.v5n6p139 URL: http://dx.doi.org/10.5539/mas.v5n6p139

Abstract

In this study a non-parametric method of Data Envelopment Analysis (DEA) is used to estimate the energy efficiencies of cucumber producers based on eight energy inputs including human power, diesel fuel, machinery, fertilizers, chemicals, water for irrigation, electricity and seed energy and single output of production yield. Data were collected using face-to-face surveys from 25 greenhouses in Khuzestan province of Iran. Energy indices, technical, pure technical and scale efficiencies were calculated by using Data Envelopment Analysis (DEA) approach for 25 cucumber greenhouses. Total energy input and output were calculated as 163994 MJha^{-1} and 62496 MJha^{-1}, respectively, whereas diesel fuel consumption with 45.15% was the highest level between energy inputs. Energy output-input ratio, energy productivity and net energy gain were 0.38, 0.47 kg MJ^{-1}, -101498 MJ ha^{-1}, respectively. The average values of TE, PTE and SE were 88%, 91% and 96%, respectively.

Keywords: Data envelopment analysis, Efficient units, Greenhouse cucumber, Technical efficiency

1. Introduction

The high rate of population growth and reducing the extent of fertile land due to the increasing development of urban and industrial areas induce more efficient use of existing facilities. The effective and efficient use of limited resources like water, soil and human power that are of particular importance to provide food requirements for people in developing countries, including Iran. Successful efforts to achieve self sufficiency and growth of gross national income like any other activity requiring deep knowledge of the practical and economic processes and applying the latest knowledge and technology around the world. Greenhouse production technology led to increase the efficiency of limited water and soil resources. And its importance is undeniable with respect to the dry climate and low rainfall in most parts of Iran. The major disadvantage of this method is high energy consumption because in most cases greenhouse production is off-season. Increase in energy efficiency in greenhouse cultures is of the most important energy studies in agriculture, and any success in increasing energy efficiency in greenhouse cultures can cause efficient use of valuable energy resources.

In recent years, Data Envelopment Analysis (DEA) has become a central technique in productivity and efficiency analysis applied in different aspects of economics and management science that helps us to manage efficient use of resources and ultimately more profit. The DEA is a non-parametric method for estimating the production function. The major drawback of these methods is initial necessary for the production function consequently parametric methods are not suiTable for evaluation the units under control that may be inconsistent with the nature of the units under evaluation (Gheisari et al., 2007).

Also in recent years, many authors applied DEA in agricultural enterprises; such as: evaluation efficiency of greenhouse strawberry (Banaeian et al., 2011), optimization of energy consumption for apple production (Mousavi-Avval et al., 2011a), a comparative study of parametric and non-parametric energy use efficiency in paddy production (Nassiri and singh, 2010), energy use pattern and benchmarking of selected greenhouses in Iran

(Omid et al., 2011), study on energy use pattern and efficiency of corn silage in Iran (Pishgar komleh et al., 2011), analysis farming system in citrus farming in Spain (Reig-Martinez and Picazo-Tadeo, 2004), improving energy use efficiency of canola production (Mousavi-Avval et al., 2011b), energy use efficiency for walnut producers (Banaeian et al., 2010).

The aim of this research was to determine energy use pattern and energy use efficiency in the cucumber greenhouses in Khuzestan province using data envelopment analysis (DEA) and presentation methods for optimization energy consumption.

2. Materials and methods

2.1 Selection of case study region and data collection

This study was conducted in Khuzestan province of Iran. This province is located within 29°58′ and 30°04′ North latitude and 47°41′ and 50°39′ east longitude, in the south-west of Iran. In this province, there are 38 vegeTable greenhouses (Anonymous, 2010). In this study, 25 active vegeTable greenhouses were studied to determine energy use and to evaluate the performance for greenhouse cucumber production.

Data were collected through personal interview method in a specially designed schedule for this study. The collected data belonged to the 2010/11 production year.

2.2 Energy equivalents of input and output

The data included the quantity of various energy inputs used per hectare of greenhouse cucumber production including: human power, machinery, diesel fuel, chemicals, water for irrigation, electricity, fertilizers and seed, and the production yield as output. In order to analysis the performance of greenhouses from an energy use efficiency point of view, all of inputs and output were then converted into energy equivalents by multiplying the quantity of input use with their corresponding energy equivalent coefficients. Energy equivalents, shown in Table 1, were used for estimation; these coefficients were adapted from several literature sources that best fit the conditions in Iran.

Following the calculation of energy input and output equivalents, the indices of energy consumption including energy ratio, energy productivity and net energy gain were estimated using the following Eqs. (Rafiee et al., 2010):

$$\text{Energy ratio} = \frac{\text{Energy Output (MJ ha}^{-1})}{\text{Energy Input (MJ ha}^{-1})} \tag{1}$$

$$\text{Energy productivity} = \frac{\text{Cucumber Output (kg ha}^{-1})}{\text{Energy Input (MJ ha}^{-1})} \tag{2}$$

$$\text{Net energy gain} = \text{Energy Output (MJ ha}^{-1}) - \text{Energy Input (MJ ha}^{-1}) \tag{3}$$

2.3 Data envelopment analysis technique

Data envelopment analysis (DEA) is an analysis method to measure the relative efficiency a homogeneous number of organizations that essentially perform the same tasks (Cooper et al., 2006). In this case, they are cucumber greenhouses. So, the values of energy consumed from different energy inputs (MJ ha^{-1}), as mentioned above, were defined as input parameters, and the yield of greenhouse cucumber production (kg ha^{-1}) was defined as output parameter; also, each greenhouse was called a decision making unit (DMU).

In DEA, an inefficient DMU can be made efficient either by reducing the input levels while holding the outputs constant (input oriented); or symmetrically, by increasing the output levels while holding the inputs constant (output oriented) (Mousavi-Avval et al., 2011b). The choice between input and output orientation depends on the unique characteristics of the set of DMUs under study. In this study the input oriented approach was deemed to be more appropriate because there is only one output while multiple inputs are used; also as a recommendation, input conservation for given outputs seems to be a more reasonable logic (Galanopoulos et al., 2006); so the greenhouse cucumber yield is hold fixed and the quantity of inputs energy were reduced.

DEA has two models including CCR and BCC models. The CCR model is built on the assumption of constant returns to scale (CRS) of activities, but the BCC model is built on the assumption of variable returns to scale (VRS) of activities. Efficiency by DEA is defined in three different forms: overall technical efficiency (TE_{CCR}), pure technical efficiency (TE_{BCC}) and scale efficiency (SE).

2.3.1 Technical efficiency

Technical efficiency (TE) can be calculated by the ratio of sum of weighted outputs to sum of weighted inputs (Cooper et al., 2006):

$$\text{Technical efficiency} = \frac{\text{weighted sum of outputs}}{\text{weighted sum of inputs}} \tag{4}$$

Or mathematically as (Nassiri and Singh, 2009):

$$\theta = \frac{\sum_{r=1}^{n} u_r y_{r,j}}{\sum_{s=1}^{m} v_s x_{s,j}} \tag{5}$$

Where 'x' and 'y' are inputs and outputs, 'v' and 'u' are input and output weights, respectively, 's' is the number of inputs (s = 1, 2, …, m); 'r' is the number of outputs (r = 1, 2, ..., n); and 'j' represents j^{th} DMU (j = 1, 2, ..., k). For solving Eq. (5) the following linear program (LP) was developed by Charnes et al., which called CCR model:

$$\text{Max: } \theta = u_1 y_{1i} + u_2 y_{2i} + \cdots + u_r y_{ri} \tag{6}$$

$$\text{Subject to: } v_1 x_{1i} + v_2 x_{2i} + \cdots + v_s x_{si} = 1 \tag{7}$$

$$u_1 y_{1j} + u_2 y_{2j} + \cdots + u_r y_{rj} \le v_1 x_{1j} + v_2 x_{2j} + \cdots + v_s x_{sj} \tag{8}$$

$$u_1, u_2, \ldots, u_r \ge 0 \tag{9}$$

$$v_1, v_2, \ldots, v_s \ge 0, \text{and (i and j} = 1,2,\ldots,k) \tag{10}$$

Where θ is the technical efficiency (TE_{CCR}) and i represents i^{th} DMU (Houshyar et al., 2010).

2.3.2 Pure technical efficiency

In 1984, Banker et al. introduced a model in DEA, which was called BCC model to draw out the technical efficiency of DMUs. The calculation of efficiency in BBC model is called Pure Technical Efficiency and can be expressed by Dual Linear Program (DLP) as (Houshyar et al., 2010):

$$\text{Max: } Z = uy_i - u_i \tag{11}$$

$$\text{Subject to: } vx_i = 1 \tag{12}$$

$$-vX + uY - u_o e \le 0 \tag{13}$$

$$v \ge 0, u \ge 0 \tag{14}$$

2.3.3 Scale efficiency

Based on the CCR and BCC scores, scale efficiency defined by (Cooper et al., 2006):

$$SE = \frac{TE_{CCR}}{TE_{BCC}} \tag{15}$$

In other words decomposition of Eq. (15) can be defined by:

$$TE_{CCR} = TE_{BCC} \times SE \tag{16}$$

This decomposition, which is unique, depicts the sources of inefficiency, i.e., whether it is caused by inefficient operation (PTE) or by disadvantageous conditions displayed by the scale efficiency (SE) or by both. If the scale efficiency is less than 1, the DMU will be operating either at decreasing returns to scale (DRS) if a proportional increase of all input levels produces a less-than-proportional increase in output levels or increasing return to scale (IRS) at the converse case. This implies that resources may be transferred from DMUs operating at DRS to scale to those operating at IRS to increase average productivity at both sets of DMUs (Pishgar komleh et al., 2011). By solving of CCR and BCC models, the weights of remaining inputs (diesel fuel, chemicals, electricity, machinery, water for irrigation, human power, fertilizers and seed) and output (greenhouse cucumber) would be calculated so the maximum value of θ is calculated.

The data analysis was carried out with help of the Excel 2007 spreadsheet and Frontier Analyst Professional software.

3. Results and discussion

3.1 Analysis of energy input and output in greenhouse cucumber production

Amount of inputs, output and their energy equivalents for greenhouse cucumber production is presented in Table 2. The total energy consumption for greenhouse cucumber production was calculated as 163994 MJ ha^{-1}; also, the percentage distribution of the energy associated with the inputs is seen in Table 3. It is evident that, the greatest part of total energy input (45.15%) was consumed by diesel fuel consumption. Also, fertilizers and seed were the second main energy consuming input. Similar studies had also reported that diesel fuel and fertilizers were the most intensive energy inputs (Zangeneh et al., 2010; Esengun et al., 2007; Cetin and Vardar, 2008; Ghasemi Mobtaker et al., 2010). ListenRead phoneticallyIn Khuzestan province is used –however short term- of heating systems in greenhouses due to the large temperature difference between day and night and the low temperature at night. Therefore diesel fuel consumption is allocated to the share largest from other inputs. In order to improve the greenhouse environment as well as reduction of diesel fuel consumption, it is strongly suggested that the heating system efficiency is raised or replaced with alternative sources of energy such as natural gas and solar energy (Omid et al., 2011).

The results also revealed that electricity was the third main energy consuming input because of rising temperatures on some days; the ventilation system is used to regulate the greenhouse temperature. ListenRead phonet the water for irrigation was the least energy demanding inputs for greenhouse cucumber production. On the other hand, the average cucumber yield obtained was found to be 78120 kg ha^{-1}; accordingly, the total energy output was calculated as 62496 MJ ha^{-1}, in the enterprises that were analyzed. In the previous study on greenhouse cucumber production in Tehran province of Iran the yield value of greenhouse cucumber and total output energy were reported higher than that of this study (Omid et al., 2011). The lower yield value and energy output of greenhouse cucumber production in Khuzestan province were mainly due to the mismanagement of input usage.

The energy output-input ratio, energy productivity and net energy gain of greenhouse cucumber production are presented in Table 3. Energy ratio was calculated as 0.38, showing the inefficiency use of energy in greenhouse cucumber production in Khuzestan province. It is concluded that the energy ratio can be increased by raising the crop yield and/or by decreasing energy input consumption. Similar results obtain 0.64 for the energy ratio of greenhouse cucumber production (Omid et al., 2011; Mohammadi and Omid, 2010). The average energy productivity of greenhouse cucumber production was 0.47 kg MJ^{-1}. This means that 0.47 units output was obtained per unit energy. Similar results have been reported 0.39 and 0.8 kg MJ^{-1} for the energy productivity of greenhouse cucumber production (Mohammadi and Omid, 2010). The net energy gain of greenhouse cucumber production was −101498 MJ ha^{-1}. Net energy gain is negative (less than zero). Therefore, it can be concluded that in greenhouse cucumber production, energy is being lost. Similar results obtain −53027.16 MJ ha^{-1} and −55552.83 MJ ha^{-1} for the net energy gain of greenhouse cucumber production (Mohammadi and Omid, 2010; Omid et al., 2011).

The distribution of inputs used for greenhouse cucumber production in groups of direct, indirect, renewable, and non-renewable sources is shown in Table 3. The ratio of direct and indirect energy sources are 67.52% and 32.47%, respectively. Also, there is a significant difference between renewable and non-renewable energy sources. Renewable energy sources are clean sources of energy that have a much lower impact on the environment than do conventional energy technologies. In the studied greenhouses, 94.98% of the input energy comes from non-renewable energy sources, which are finite and will someday be depleted. Also, many of these energy sources are harmful to the environment (Unakitan et al., 2010). Several researchers showed that the ratio of direct energy is higher than that of indirect energy, and the rate of non-renewable was much greater than that of renewable consumption in cropping systems (mohammadi et al., 2008; Hatirli et al., 2006).

3.2 DEA results

3.2.1 Energy use efficiency for unit greenhouses

In this study, we used CCR and BCC models to evaluate technical, pure technical and scale efficiencies (TE, PTE and SE, respectively) of cucumber greenhouses. The results of CCR and BCC models are shown in Table 4. Based on CCR results, this study shows that only 4 greenhouses were relatively efficient and the remaining 21 where inefficient, i.e. their efficiency score were below 1. But from the results of BCC model 6 greenhouses (out of total

25 greenhouses) were efficient, meaning they have an efficiency score of 1(Table 4). Other greenhouses who have efficiency score less than 1, are inefficient in energy use. The average values of the technical efficiency, pure technical efficiency and scale efficiency are summarized in Table 5. The average values (for all 25 greenhouses considered) of TE, PTE and SE were found to be 88%, 91% and 96%, respectively. The average TE of the inefficient DMUs at the greenhouse unit was calculated as 88%. This implies that the same level of output could be produced with 88% of the resources if these units were performing on the frontier. Another interpretation of this result is that 12% of overall resources could be saved by raising the performance of these DMUs to the highest level. This indicates that there is ample scope in improving inefficient greenhouses for operating practices to enhance their energy use efficiency. In a similar study, TE, PTE and SE for cucumber greenhouse were reported to be 87%, 97% and 90%, respectively (Omid et al., 2011).

3.2.2 Reference units with coefficients of decision

The efficient greenhouses obviously follow good operating practices. However, among the efficient greenhouses, some (greenhouses: 6, 11, 12 and 21) show better operating practices than others. Therefore, discrimination is required to be made among the efficient greenhouses while seeking the best operating practices. These efficient greenhouses can be selected by inefficient DMUs as best practice DMUs.

So for each inefficient unit an efficient unit or combination of efficient multi-unit as reference units is introduced. Each share of efficient units in the reference pattern for an inefficient unit depends on the weight of λ which is calculated for each of the efficient units using DEA approach (Emami meibodi, 2000).

For example, in the case of the greenhouse 5, the reference composite DMU is formed by the greenhouse 6 (Table 4, CCR model). This means the greenhouse 5 is close to the efficient frontier segment formed by this efficient DMU. The production efficiency can be obtained for greenhouse 5 with the introduction of efficient greenhouse reference 6. The selection of this efficient DMU is made on the basis of its comparable level of inputs and output yield to the greenhouse 5. In Table 4 (CCR model), the reference unit for greenhouse 5 is expressed as 6(81.7%), where 6 is the DMU number while the value between brackets is weight of reference greenhouse that shows the contribution amount of reference greenhouse 6 in evaluation of inefficient greenhouse 5.The 91.69% efficiency of the greenhouse 5 means that for being an efficient unit, it has to decrease 8.31% of all inputs (without decreasing output). On the other hand, needed inputs for a specific level of output can be calculated; by considering the greenhouse 6 as the pattern of the greenhouse 5, and decision coefficient of the greenhouse 5 in the Table 4 which is 81.7%. So to have the greenhouse 5 efficient, it has to use 81.7% of the inputs of unit 6, without decreasing output.

3.2.3 Returns to scale

The latest column of Table 5 indicated results of return to scale. The analysis shows that DMUs numbered 6, 11, 12 and 21 that are efficient under the CRS model are both technically and scale efficient (Table 5).

The RTS indicated that all efficient units (based on technical efficiency) were operating at CRS, whereas all inefficient ones were at IRS, which indicates that for considerable changes in yield, technological change is required.

3.2.4 Slack and surplus energy consumption in each of greenhouses

According to the results obtained from Table 6 greenhouses 6, 11, 12 and 21 have constant efficiency but the remains have increasing efficiency. Table 6 shows the obtained results from analyzing greenhouses by using input oriented constant returns to scale model. Data of this Table are used for determining extra input and deficiency of efficiency. The specific quantity of input that each inefficient unit needs to decrease in order to become efficient is determined. As Table 6 shows, the greenhouse 1 with the efficiency of 91.47% has to decrease 22154 units of diesel fuel, 9540 units of electricity and 7894 units of fertilizers and seed to stand on the efficiency partition line. The average share of each input in decreasing energy consumption for greenhouses is illustrated in the Figure 1.

4. Conclusion

This study described an in-depth application of input oriented DEA model to investigate the degree of technical and scale efficiency of 25 cucumber greenhouses in Khuzestan province of Iran. This procedure allows the determination of greenhouses 6, 11, 12, and 21 as the best practice greenhouses that can be providing useful insights for other greenhouse management. Diesel fuel, total fertilizers and electricity energy inputs had the highest potential for saving energy; so, if inefficient greenhouses would pay more attention towards these sources, they would considerably improve their energy productivity.

Acknowledgement

The authors are very grateful to Shahid Chamran University of Ahvaz in Iran for support to the research.

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Table 1. Energy equivalent of energy output and input in agricultural production

Inputs	Unit	Energy equivalent	Reference
1- Human power	h	1.96	Zangeneh et al., 2010
2- Fertilizers			
Potassium (K_2O)	Kg	11.15	Esengun et al., 2007
Nitrogen (N)	Kg	47.1	Canakci and Akinci, 2006
Phosphate (P_2O_5)	Kg	15.8	Canakci and Akinci, 2006
3- Chemicals			
Pesticide	Kg	101.2	Kizilaslan, 2009
Herbicide	Kg	238	Mousavi-Avval et al.,2011b
4- Machinery	Kg	62.7	Mandal et al., 2002
5- Cucumber seed	Kg	1	Mohammadi and Omid, 2010
6- Diesel fuel	Lit	56.31	Omid et al., 2011
7- Electricity	kWh	11.93	Omid et al., 2011
8- Water for irrigation	m^3	1.02	Zangeneh et al., 2010
Output (cucumber)	Kg	0.8	Omid et al., 2011

Table 2. Energy used status for cucumber production in Khuzestan province

Input	Quantity per unit area (ha)	Equivalent energy MJ/ha	Unit	Percent
a- Input				
1- Fuel consumption	1315	74047	Lit	45.15
2- Human power	4165.2	8163	h	4.97
3- Machinery	51.6	3235	Kg	1.97
4- Fertilizer (sum: potassium, nitrogen, phosphate) and seed	1050.2	39907	Kg	24.33
5- Chemicals (sum: pesticide, herbicide)	120.2	9696	Kg	5.91
6- Water for irrigation	1250	1275	Lit	0.8
7- Electricity	2319.5	27671	kwh	16.87
Total energy input	-	163994	$MJha^{-1}$	100
b- Output				
Cucumber	78120	62496	Kg	-
Total energy output	-	62496	$MJha^{-1}$	-

Table 3. Energy output-input ratio and forms in greenhouse cucumber production

Items	Unit	cucumber	Percent of total
Crop yield	kg ha^{-1}	78120	
Energy ratio	-	0.38	
Energy productivity	kg MJ^{-1}	0.47	
Net energy gain	MJ ha^{-1}	−101498	
Energy form[1]			
Direct energy[2]	MJ ha^{-1}	109881	67.52
Indirect energy[3]	MJ ha^{-1}	52838	32.47
Renewable energy[4]	MJ ha^{-1}	8163.13	5.01
Non Renewable energy[5]- renewable energy[5]	MJ ha^{-1}	154555.87	94.98
Total energy input	MJ ha^{-1}	163994	100

1. Energy equivalent of water for is not included.
2. Includes human power, diesel and electricity.
3. Includes seeds, fertilizers, chemicals and machinery.
4. Includes human power and seeds.
5. Includes diesel, fertilizers, chemicals, elect irrigation ricity and machinery

Table 4. Evaluation of cucumber greenhouses with reference units via CCR and BCC input oriented models

	BCC model		CCR model	
DMU's	reference units with coefficients of decision	Efficiency (%)	reference units with coefficients of	Efficiency (%)
1	5(78.24)	92.32	11(65.2), 6(70.12)	91.47
2	12(56.18), 21(74.67	86.5	12(37.3), 11(39.16)	83.8
3	12(38.12), 5(67.34)	95.4	11(58.4), 21(81.4)	92.15
4	12(89.34), 6(45.23)	89.32	21(84.14)	81.9
5	-	100	6(81.7)	91.69
6	-	100	-	100
7	12 (19.3), 5 (22.7)	89.91	11(56.5), 21(59.16)	87.59
8	19(70.16), 6(56.34)	90.12	6(71.8), 12(61.73)	85.56
9	19(60.18), 5(34.89)	94.7	6(81.9), 21(92.12)	89.51
10	5 (34.7), 6 (56.12)	92.84	6(69.14)	87.63
11	-	100	-	100
12	-	100	-	100
13	11(76.11), 5(71.46)	95.2	6(70.8), 21(82.71)	93.31
14	21(34.56)	91.21	12(72.9),21(81.53)	85.12
15	12(56.67)	80.8	12(80.24)	79.49
16	21(70.29), 11(45.23)	85.12	11(72.16)	83.39
17	6(22.1), 11 (39.4)	89.2	6(60.70), 11(39.13)	87.56
18	6(59.12),12(57.23)	82.3	12(50.42),21(62.5)	79.49
19	-	100	6(51.71)	90.9
20	21(30.17), 11(67.45)	90.2	21(61.2)	87.69
21	-	100	-	100
22	21(60.18), 19(86.15)	91.9	12(79.23)	89.59
23	21(35.76)	87.3	6(74.91)	85.56
24	21(41.35), 12(79.47)	80.3	11(59.3)	79.49
25	11(81.19), 21(24.9)	87.5	21(70.23)	83.39
Average of efficiency in	**-**	**91**	**-**	**88**

Table 5. Analysis of efficiency and return to scale in greenhouse cucumber production in Khuzestan province

DMU's	E_{CCR} (%)	E_{BCC} (%)	E_S (%)	Return to scale
1	91.47	92.32	99	increasing
2	83.8	86.5	96	increasing
3	92.15	95.4	96	increasing
4	81.9	89.32	91	increasing
5	91.69	100	91	increasing
6	100	100	100	constant
7	87.59	89.91	97	increasing
8	85.56	90.12	94	increasing
9	89.51	94.7	94	increasing
10	87.63	92.84	94	increasing
11	100	100	100	constant
12	100	100	100	constant
13	93.13	95.2	98	increasing
14	85.12	91.21	93	increasing
15	79.49	80.8	98	increasing
16	83.39	85.12	97	increasing
17	87.56	89.2	98	increasing
18	79.49	82.3	96	increasing
19	90.9	100	90	increasing
20	87.69	90.2	97	increasing
21	100	100	100	constant
22	89.95	91.9	97	increasing
23	85.56	87.3	98	increasing
24	79.49	80.3	98	increasing
25	83.39	87.5	95	increasing
Average	**88**	**91**	**96**	-

Table 6. Slack and surplus energy consumption in each of greenhouses with CCR input oriented model ($MJha^{-1}$)

DMU's	Efficiency	Fuel	Human	Machinery	fertilizer and seed	Chemicals	water for irrigation	Electricity	Output yield
1	91.47	22154	0	0	7894	0	0	9540	0
2	83.8	12567	1234	0	0	0	0	3570	0
3	92.15	10156	1235	1050	2315	1212	340	0	0
4	81.9	13570	1020	0	2612	1370	0	0	0
5	91.69	22189	0	561	2500	0	245	0	0
6	100	0	0	0	0	0	0	0	0
7	87.59	12156	0	0	0	3890	550	7912	0
8	85.56	3156	2719	0	0	1920	0	6512	0
9	89.51	0	2930	0	0	1900	0	9560	0
10	87.63	8912	1350	570	3690	0	560	0	0
11	100	0	0	0	0	0	0	0	0
12	100	0	0	0	0	0	0	0	0
13	93.31	12340	2560	0	1230	0	110	2154	0
14	85.12	11512	3210	0	2590	0	0	5420	0
15	79.49	1240	2300	0	10400	0	0	12380	0
16	83.39	13580	0	1200	13890	0	220	0	0
17	87.56	9240	1100	590	3780	1210	0	0	0
18	79.49	13470	1241	0	13100	0	670	0	0
19	90.9	12610	0	1200	0	4129	0	5810	0
20	87.69	16280	3109	0	2280	1340	0	14150	0
21	100	0	0	0	0	0	0	0	0
22	89.59	16800	1300	1230	6800	0	820	2130	0
23	85.56	14500	0	0	10200	0	0	9100	0
24	79.49	39708	0	3400	1200	0	560	0	0
25	83.39	18950	1230	0	13460	1670	0	2450	0

Table 7. Nomenclature

Nomenclature	
BCC	Banker–Charnes–Cooper (DEA
CCR	Charnes–Cooper–Rhodes (DEA
CRS	Constant Returns to Scale
DE	Direct Energy
DEA	Data Envelopment Analysis
DMU	Decision Making Unit
DRS	Decreasing Returns to Scale
IDE	Indirect Energy
IRS	Increasing Returns to Scale
NRE	Non-Renewable Energy
RE	Renewable Energy
SE	Scale Efficiency
PTE	Pure Technical Efficiency
TE	Technical Efficiency
DLP	Dual Linear Programming
LP	Linear Programming

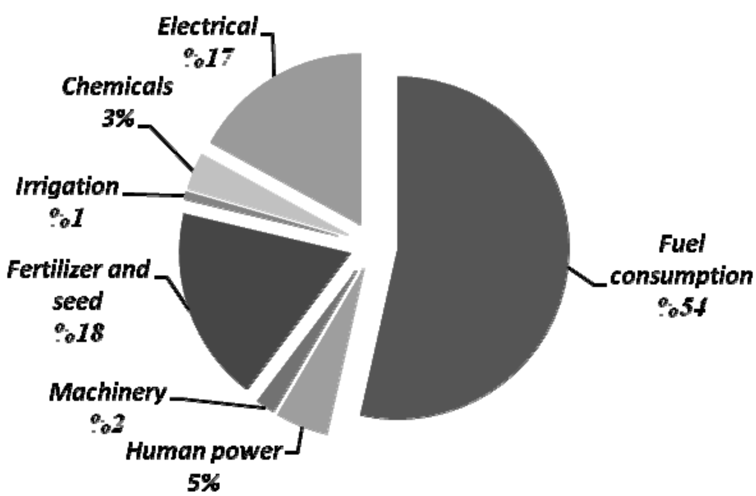

Figure 1. Energy saved via each input with CCR input oriented in cucumber greenhouses