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Evaluation of Efficiency and Environmental Effects of Greenhouses in Hyrcanian Zone Using Data Envelopment Analysis (DEA)

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Abstract

Mankind has always been faced a problem called 'Limitation of Resources and Production Facilities' in a way that even now and in spite of the increased development of sciences and techniques, this limitation not only exists, but also due to the ever-increasing growth of the population on one hand and the destruction of the environment on the other hand, it has even been intensified. At the moment, higher productivity and efficiency and efficient use of the existing facilities is practically more than a choice and has become a necessity. The objective of this article is to measure the efficiency of greenhouses in Guilan province as sample of Hyrcanian zone. The present research is the survey type and required data were collected through questionnaires from 60 greenhouses in the province in 2009. Data envelopment analysis (DEA) was the method that used for measuring the efficiency of greenhouses and rating them. Results showed that among 60 greenhouses, 18 were efficient and on the efficiency frontier. It is noteworthy that the mean efficiency of this industry should be at least 75.30%.

Keywords: Data Envelopment Analysis (DEA), Efficiency, Environmental Effects, Food Security, Greenhouse, Hyrcanian zone

Introduction

In all past centuries and ages throughout the world, execution has always been the hardest and greatest punishment. In other words, mankind has accepted that the most precious thing which can be taken from him is their life. Therefore, whichever thing that ends up in keeping them alive must be naturally considered valuable. There are several factors which play key roles in keeping one alive. After water, food is the most common and important of all. To continue living a good life, we need food for every day of our lives. According to the conducted computations, in average, every human being needs 50 tons of agricultural products (food) in his or her life. When added up, this need is both a large figure and a permanent and continuous necessity whose satisfaction can not be postponed to the future and to providing facilities. Not eating food, even for a few days, causes problems and can't be tolerated for a longer period. Usually, food insecurity at household and country levels results in social-economic insecurities and at international level, it might lead to bloodshed and war. Throughout centuries, mankind has always considered providing food for himself and then for his family as the most important activity of life. As time passed and upon the emergence of cities and countries, this became a national concern. With the flourishing of the development economy market, self-reliance and self-sufficiency theories and above all, the nutrition self-sufficiency theory became one of the main issues of national enlightenment discussions and even now, despite many ups and downs, it still is one of the important dialogues and a national economic policy of many countries (Nouri Naeini, 2000).

Environmental aspects of greenhouse cultivating have been caused most of the countries start to developing this Industry by employing exact plans. As an illustration, low use of valuable recourses such as water during summer days, is one of the most important environmentally friendly aspects of greenhouses. Moreover, optimum and controlled use of chemical materials which are so dangerous for environment, high producing in each hectare might be considered as environmental benefits of greenhouse cultivating.

Population growth and consequently, the demand for providing agricultural products and also the seasonal production of these products have caused strategies to be considered for meeting people's needs so that not only the production level is increased, but also producing out-of-season products would be possible. One of these strategies is to cultivate agricultural products (such as fruits and vegetables) in greenhouses. By doing so, besides the increased production rate, some production measures can be taken in all seasons as well. Using environmental factors-controlling techniques is beneficial especially in regions, where the natural conditions of the essential factors of plant growth (soil and water) can be made suitable only by irrigation, weeding, applying fertilizers, etc. It's been years since greenhouse cultivation is being practiced in Europe with many economic and profitability justifications (Sharifi, 2005). Producing greenhouse products in Iran has been taken into consideration due to global conditions. Of course, developing greenhouses in this country has

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its own advantages and disadvantages. Of the main advantages of this practice, a more efficient use of resources, permanent supplies, more job creation and higher yields can be mentioned. On the other hand, some of the most important disadvantages of this industry are the need for larger investments, higher technical knowledge, hygiene issues and environmental consequences. (Mehrabi, 2007).

On the other hand, optimum allocation of resources in an organization, enterprise or industry requires a continuous assessment of the performance of its units. Performance evaluation is one of the elements of the productivity improvement process because without measurement, making judgments would not be feasible and as a result, a proper controlling and planning could be impossible for the organization. Measuring the said concepts have always been as object of attention for experts of different sciences including management, accounting, economics, engineering and mathematics and many researches have been done in this regard in a way that since 1965, when the first productivity measurement model was proposed by Kendrick-Creamer, many productivity and efficiency-measurement models have been presented by different individuals and global organizations. One of these models is the mathematical model of data envelopment analysis (DEA) (Motameni, 2002). This method is based on linear programming and since it's an optimization method, it is advantageous over other efficiency analysis methods. With consideration of the characteristics of DEA and its being capable of providing a comprehensive and conclusive method for every unit of multiple inputs and outputs, it seems to be a suitable method for computing the efficiency of economic enterprises. Moreover, the possibility of considering variables for this model and using shadow prices causes it to be applied for assessing the efficiency of service-providing, non-profit-making and governmental sectors as well (Rahmanian, 2008).

Since the millennium development goals (MDGs) were approved in September 2000, planning and implementing economic reforms with the purpose of reducing poverty has become one of the most important issues of the global development. Hence, in 2005, a broad range of measures for reducing poverty and hunger including agricultural development and producing food products in rural areas, where hunger is quite obvious, was taken into consideration. Therefore, to achieve the MDGs, the United Nations introduced several new strategies and guidelines in its publications among which attempting to increase the productivity (efficiency) of the agriculture sector is an important one (Iran economy, 2006). The concept of food security and the nutritional needs of the people around the world are described in the first part of this article. Then, the mathematical method of the present research (DEA) is stated along with the evaluation and presentation of a strategy for increasing the yield and efficiency as a way of meeting the increased nutritional needs.

Food Security and Increased Nutritional Needs

According to one of the most recent definitions of food security that was given in 1996, "Food security exists when all human beings have easy access to healthy, sufficient and nutritious foods, which satisfy the nutritional needs of a healthy and active individual." Based on this definition, the food security of a society is achieved when the risk of not having access to enough food at the household level is low. On the other hand, healthy nutrition occurs when the risk of not having access to necessary nutrients for maintaining cellular life is minimized. The two given definitions have many similarities. In addition, a society's movement towards achieving these goals is faced with much interference. As a whole, food security deals with the capability to eat food at the household level and healthy nutrition emphasizes on the substances required for cellular life. Applying the above-mentioned concepts and definitions to provide food and a society's health requires a systematic understanding of food and nutrition. In this system, household is the smallest unit that chooses its own nutrition basket using its potential capability. In the process of movement from potential capability to the realities of consumption and health, issues such as preferences and the behavioral pattern of a household (allocation of resources), type of eating food and taking care of the family members' health are considered as important factors, which are affected by the culture and the household's nutrition literacy. To sum up, it can be said that providing food security and guaranteeing nutrition at the household level depends on four factors: physical access (food at the place of residence), foods prepared without any harmful or even pathogenic substances and containing minerals instead, culture and nutrition literacy for having an economic access to foods (income and prices) (Iran economy, 2006). Food security is a complicated and multi-dimensional issue that can be only comprehensively considered through active cooperation and interaction between all social institutions, organizations and groups (FAO). In a general classification, effective factors of food security can be divided into two groups: A) production-related factors (supply), consumption (demand) and trading foods and B) factors that indirectly and through affecting the main factors, affect food security and include wars, revolutions, droughts, storms, floods or cultural factors such as the consumption pattern of a society (Bakhtiyari and Haghighi, 2003).

Based on the published statistics of the UN's Department of Economic and Social Affairs, the world's population in 2007 reached over 6,671,000,000 people. Of this population, only 1,223,000,000 people, i.e. about 18% of the world's population live in developed regions, while the rest live in the developing regions (*Table 1*). Also, Asia with 4,030,000,000 people has more than 60% of the world's population. The said department has predicted that if the current growing trend of the world's population continues, there would be about 10% of the world's population living in developed regions in the year 2050; while the rest will be living in the developing regions and Asia would still have the largest share of the world's population (www.koaj.ir).

Table 1- Prediction of the world's population for the year 2050 in case the previous trend continues (in millions)

Main Region	1950	1975	2007	2050
The World	2535.093	4076.08	6671.226	11857.79
Developed Regions	813.5609	1048.104	1223.004	1218.291
Developing Regions	1721.532	3027.977	5448.223	10639.5

Source: Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat (2007).

According to predictions, a major part of the world's population growth results from the growing population in the developing countries such that in the period of the years 2045-2050, only the name of 'The United States of America' can be seen in the list of the countries with the highest population growth rate.

Although in the future, the demand for food and relevant products will be lower than before, given this trend, meeting the demands requires increased areas of cultivated lands and higher yields of products would be achieved by introducing new cultivars and improving agricultural technologies. However, questions are raised for each of the above-mentioned factors: Are there enough water resources and lands for increasing the extent of wetland and dry land farming up to a required level or the world will be facing the shortage of these vital resources? Do considerable potentials for increasing the yield still exist or yield levels have already reached close to their capacity limits and there is no place for any more increases? Is biotechnology capable of introducing a new generation of prolific cultivars that can adapt to undesirable environments?

Usually, an increase in agricultural productions depends on three main factors:

1) Increased cultivated area
2) Increased cultivation density
3) Yield increase

Since the early 1960s, yield increase has been the most important factor of increased agricultural productions in the world in a way that during the 1961-1999 period, approximately four fifth or 78% of the total production increase resulted from yield increase, while 7% of it was the result of increased cultivation density and only 15% of the production increase was related to increased cultivated area (www.koaj.ir).

On the other hand, nowadays, growing and supplying agricultural products throughout the year has become a common practice. Advances in different agricultural sciences and the progress and developments in artificial environments that have been made through using suitable conditions, have eliminated the interval between seasons, which besides providing various products with superior quality has made job and income creation in the agriculture sector possible (Abdolkarimzadeh, 2005). To continue living, supplying water is one of the necessary requirements in agriculture and in order to be adapted to the environment, an optimum use of soil and water resources is unavoidable. Usually, shortage of water is one of the problems of economic development and whatever assistance in improving the condition of this sector can be a step taken towards economic development, especially in rural areas. Population growth and consequently, the demand for producing agricultural products and also the seasonal production of these products have caused some strategies to be considered for meeting people's needs so that not only the production rate is increased, but also producing out-of-season products would be possible. Cultivating products (such as fruits and vegetables) in greenhouses is one of these strategies. Therefore, besides an increase in the production rate, a given product can be produced in every season as well. In fact, using the techniques of controlling environmental factors, especially in regions where weather conditions are undesirable, has proved to be more valuable (Sharifi, 2008). The economic aspects of greenhouse cultivation have caused countries to make more precise plans with development purposes in mind. For instance, the minimum water requirement of every 1000m^2 of a greenhouse for 24 hours in summer, when the consumption rate reaches its peak, is 8-10m^3. The most important advantage of greenhouse productions is high job-creation rates, an optimum and controlled use of agricultural inputs, high yields per hectare and an out-of-season and continuous production. Production in a controlled environment and an optimum use of rare and valuable water resources and lands are some other advantages of this type of production (Abdolkarimzadeh, 2006).

Efficiency issues were first mentioned in their written and systematic forms in the studies and investigations of Debro and Kopmans and were continued by Farrell in 1957, but the practical measurement of efficiency became possible in 1977 (SFA econometrics method) and 1978 (DEA linear programming method) (Emami Meibodi and Izadi, 2008). Efficiency is the explanation of the concept that with what quality an organization has used its resources for having the best production performance during a given period of time (Piece, 1997). In fact, efficiency is the criterion for an organization's performance, which is established upon the amount of resources (inputs). In other words, it is the amount of resources that are used to produce a certain amount of a product. Generally, efficiency is calculated by the relationship between the output-input proportions (Mehrgan, 2004). It is a very important, yet complicated concept (from an operational perspective, to evaluate it by taking all its effective factors into account), which has been more frequently studied by engineers, managers and economists (Pourkazemi and Ghazanfari, 2005). Data envelopment analysis is a method which is applied to assess the efficiency and productivity of units that are responsible for using resources to obtain a desirable output. It may include several inputs and outputs without the need for predetermined weights (e.g. index method) and the clear specifications of the relationships between inputs and outputs (e.g. the regression method) (Bowlin, 1998). DEA is a linear programming method which forms an efficient frontier using information from organizations and production units as decision-making units (DMUs). The said frontier is created based on information in the form of inputs and outputs and according to the results of a consecutive linear programming. In fact, it is the inefficiency degree of each DMU to the distance between this unit and the efficiency frontier (Emami Meibodi, 2005). Due to its unique capabilities, data envelopment analysis has become one of the common methods for performance evaluation and many of the researches in this field use it for this purpose and for assessing productivity as well. These capabilities have caused the said model to be used in the industry sector, financial services (banks, insurance, etc) and transportation, educational and research centers, health and treatment centers and so on. ‘Measuring the Technical Efficiency in Malaysian Manufacturing Industries Using the Deterministic Production Frontier Function’ is one of the researches in which this method was used by Wadonda (1988). In this research, the efficiency of several industries including tea-producing factories in Malaysia during 1984-1988 was assessed using DEA technique. Obtained results revealed that the highest efficiency of the tea-producing industry was 72% in 1984, while the lowest efficiency was 44% in 1988 (Wadonda,1998). Also, Xueming Luo’s study on ‘Evaluating the Profitability and Marketability Efficiency of Large Banks’ investigated 245 large banks in 2003 and dealt with the evaluation of their profitability and marketability efficiencies. This research provides many evidences on the relatively lower marketability efficiency of large banks (Xueminng, 2003). Furthermore, Kavousi (2007) conducted a research on ‘Evaluating and Analyzing the Effective Factors of Rice Transformation Industries’ Productivity’ using DEA method and the production function. This research was done on 130 rice transformation enterprises in Iran and its results showed that 19 enterprises were on the efficiency frontier. Some of the factors which affected the efficiency were also analyzed (Kavousi and Ebrahimpour, 2007).

Materials and Methods

Assessing the efficiency of greenhouses in Guilan province in 2008 has been the main objective of this research. In 2004, a total of 284 greenhouses were active in different towns of the said province; however, due to the heavy snow in that year, only 120 of them remained of which 64 greenhouses were active and under cultivation in 2009, when questionnaires were distributed and thus, the required data were collected. These 64 identified active units were considered as the statistical population. After determining the needed population, a questionnaire was designed in which many aspects such as the general specifications of greenhouses, type of greenhouse covers, their surface areas, infrastructure facilities, raw materials to be applied, energy and fuel costs, working manpower number and cost, production rate, sales prices of the produced products, etc. were taken into account. Required data were collected by distributing questionnaires among the said units. Due to not having access to greenhouse owners and some incomplete questionnaires, four questionnaires were eliminated. After processing the data, EMS software was used for the DEA model.

The modified BCC envelopment model of the input axis was used in this research. In the model, θ shows the proportion of the reduction of the studied unit’s inputs for improving efficiency. Here, a unit is efficient only when the two following conditions exist:

a) θ^x =1 and

b) All the auxiliary variables have zero values.

$$\min y_0 = \theta - \sum_{\gamma=1}^{s} \varepsilon s_\gamma^+ - \sum_{i=1}^{m} \varepsilon s_i^- \quad (1)$$

St:

$$\sum_{j=1}^{x} \lambda_j y_{\gamma j} - s_\gamma^+ = y_{\gamma 0} \quad (\gamma = 1 \ldots s)$$

$$\sum_{j=1}^{x} \lambda_j x_{\gamma j} + s_i^- = \theta x_{i0} \quad (i = 1 \ldots m)$$

$$\sum \lambda j = 1 \qquad \theta = \text{Free for mathematical signal}$$

$$s_j^+, s_j^- \geq 0 \quad (j = 1 \ldots n)$$

By solving the above-mentioned model for the studied units, two, Efficient’ and ‘Inefficient’ groups were identified. Those units whose efficiency score was 1 were determined as efficient units. Inefficient units could be rated by getting efficiency scores; however, units whose efficiency score was 1 could not be rated using classic DEA models. Therefore, the A&P model was proposed by Anderson and Peterson, which made determining the most efficient units possible. Using this technique, the score of efficient units could be more than 1 (100%).

In order to assess the efficiency by the DEA method, suitable inputs and outputs were selected first. Then, research inputs and outputs were selected to assess the efficiency of greenhouses as follows:

Inputs

L: Manpower cost; a payable value (in Iranian Rials) for rewarding the workers in 2008.

M: Value of production inputs (seeds, herbicides and pesticides, fertilizers and minerals) in Iranian Rials.

E: Energy; total payable cost for energy consumption in 2008.

H: Cultivated area (in meters).

Output

Y: Income; value of various greenhouse products in 2008 (in Iranian Rials).

Objective Function

Q: Efficiency of greenhouses in 2008.

Results

After distributing and collecting the questionnaires, 60 of the completed and received questionnaires were studied for assessing the efficiency and also for rating greenhouse units. Some of the questionnaires were received as incomplete, which after more visits, they were modified and completed. Of the existing models, the modified BCC envelopment model of the input axis of the data envelopment analysis was selected to assess the efficiency of greenhouse units in Guilan province. The reason for selecting BCC model was that according to the opinions of experts in this industry, increasing inputs does not lead to output increase in the same proportion, which means the variability of efficiency with scale. Furthermore, since several inputs and only one output is considered for assessing the efficiency, the input axis model, which reduces inputs by keeping the output constant was selected. By solving the above-mentioned model for greenhouses, the efficiencies of 18 units became 1 or 100% (Q= 1) and formed the efficiency frontier. Forty-two other greenhouses had efficiency values of less than 1 (or <100%) (Q<1), which was an indication of their inefficiency. Then, by solving the A&P model for 18 greenhouses, whose objective function equaled 1, the ratings of efficient units were done and therefore, all greenhouses were rated. The output related to solving the aforesaid models is given in table 2.

Table 2- Efficiencies of decision-making units (DMUs)

Greenhouses	Efficiency	Reference Units	Greenhouses	Efficiency	Reference Units
1	80.00%	23, 27	31	120.49%	18
2	79.87%	23, 31	32	102.86%	6
3	1176.47%	14	33	74.42%	23, 31, 35, 41
4	100,00%	3	34	91.93%	13, 40, 48, 51
5	62.66%	23, 32, 48	35	115.37%	20
6	59.34%	3, 20, 23, 35, 51	36	77.78%	3, 40, 48
7	54.92%	3, 23, 41, 51	37	83.29%	3, 40, 48, 51
8	54.06%	13, 40, 48, 51	38	58.18%	23, 27, 31
9	77.90%	40, 48, 51	39	102.59%	1
10	67.04%	20, 23, 31	40	102.42%	9
11	51.48%	3, 23, 27, 35	41	140.88%	4
12	30.40%	13, 40, 48, 51	42	75.25%	13, 23, 35, 48, 51
13	107.55%	18	43	90.54%	3, 35, 41, 48, 51
14	59.39%	13, 20, 35, 51	44	62.98%	13, 40, 48, 51
15	100.00%	3	45	68.32%	13, 31, 35, 48
16	60.11%	13, 40, 48, 51	46	71.12%	13, 23, 35, 48, 51
17	68.68%	13, 23, 35, 48, 51	47	25.69%	23, 31, 32
18	76.08%	3, 20, 23, 35, 51	48	264.67%	23
19	58.10%	3, 20, 35, 51	49	82.34%	3, 48, 51, 52
20	132.03%	15	50	37.94%	20, 23, 31
21	64.12%	3, 20, 23, 35, 51	51	100.00%	25
22	36.52%	23, 27, 31, 35	52	291.67%	1
23	385.26%	21	53	59.74%	20, 23, 31, 51
24	72.55%	13, 23, 35, 48, 51	54	49.57%	3, 35, 48
25	56.86%	13, 31, 48, 51	55	61.73%	3, 20, 23, 35, 51
26	54.28%	31	56	79.31%	31, 35, 39
27	129.69%	5	57	74.12%	3, 27, 35
28	100.00%	3	58	72.81%	13, 20, 31, 51
29	88.66%	3, 40, 48, 51	59	100.00%	4, 13, 15, 20, 28, 32, 48
30	51.84%	31, 35, 41	60	56.17%	13, 20, 23, 35, 51

In the above table, columns 1 and 4 indicate the number of DMUs. Columns 2 and 5 show the efficiency of those units, while columns 3 and 6 show the reference units or the pattern for each unit. In other words, for an inefficient unit in the above table to become efficient and be transferred to the efficiency frontier, a convex composition of its reference units should be found. This composition in the said model has the same value of the coefficient of reference units multiplied by the values of the given unit's inputs. As mentioned before, units whose efficiency scores are less than 1 are identified as inefficient and can be rated by getting an efficiency score. However, units whose efficiency score is 1 (100%) can't be rated using classic DEA models. Therefore, efficient units have been rated by the A&P model, proposed by Anderson and Peterson. To analyze the software's output, at first, the modified BCC model of the input axis was implemented for all greenhouses (60 units) using EMS software and then, outputs obtained from solving the models were taken. Solving all 60 research models provided different information. The efficiency of each greenhouse unit has been given in table 2.

As seen, 18 greenhouses, i.e. 3, 4, 13, 15, 20, 23, 27, 28, 31, 32, 35, 39, 40, 41, 48, 51, 52 and 59 with values of 100% or more had the highest efficiencies. Also, the A&P model was used for rating 18 units that were on the efficient frontier. Based on this rating, greenhouse number 3 was at the highest level. Average efficiency in this industry is 75.30%.

Moreover, the efficiency of the existing greenhouses is given in four classifications in table 3. In this table, no greenhouse has an efficiency less than 20%, 7% of them have an efficiency of 20%-40%, the efficiency of 22% of the greenhouses is at the range of 40%-60%, 33% of them have an efficiency of 60%-80%, while the efficiency of 38% of the greenhouses is more than 80%. The following diagram is given for a better comparison.

Table 3- Classification of the efficiencies of greenhouse units

Classification	Efficiency (%)	Frequency of Greenhouses (N)	Frequency of Greenhouses (%)
1	0-20	0	0

2	20-40	4	7
3	40-60	13	22
4	60-80	20	33
5	80-100	23	38
Total		60	100

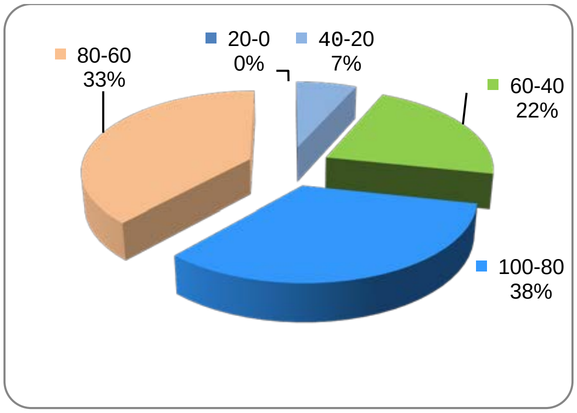

Figure 1- Classification of the efficiencies of greenhouse units

Regarding the efficiency, most of the greenhouse units are in the 80-100 classification (23 greenhouses, 38%), (Figure 1)

Then, in order to apply the results obtained from the DEA method, the interpretation of the software's output is expressed. Thus, output information obtained from solving the model for greenhouse number 5 (DMU 5) is analyzed:

1. The objective function's value, that shows efficiency, is Q= 62.66%, i.e. the company's efficiency is 62.66%. In other words, it is inefficient.
2. With consideration of the model's output shown in table 3, the reference units of greenhouse number 5 are greenhouse numbers 23, 32 and 48. Thus, inputs of the virtual unit 5 are computed as follows:

$$D_{23}\text{ (inputs of unit 23)} + D_{32}\text{ (inputs of unit 32)} + D_{48}\text{ (inputs of unit 48)}$$

$$0.81\begin{bmatrix}1{,}600{,}000\\1{,}325{,}000\\200{,}000\\700\end{bmatrix} + 0.15\begin{bmatrix}12{,}500{,}000\\2{,}160{,}000\\2000{,}000\\500\end{bmatrix} + 0.04\begin{bmatrix}64{,}000{,}000\\4{,}250{,}000\\3{,}000{,}000\\500\end{bmatrix} = \begin{bmatrix}5{,}731{,}000\\1{,}567{,}250\\582{,}000\\662\end{bmatrix}$$

This output expresses that for greenhouse 5 to reach the efficiency frontier, it should cause its input values to be equal to that of the virtual unit. In other words, it must reduce its manpower cost to IRR. 5,731,000. Moreover, it should reduce its fertilizer, seeds and minerals consumption to IRR. 1, 567,250, its payable cost of energy to IRR. 582,000 and its cultivated area to 662m^2 compared with the amount of the harvested product. This interpretation is applicable to all DMUs so that managers can be informed of how to efficiently use their production resources.

Conclusion

Studying the trend of the population growth in the world and as a result, increased demands for food and agricultural products along with the damages caused by the population growth, mankind's greed and also the intensive destruction of the environment have made the use of new agricultural methods unavoidable. In fact, the global community has no choice but to use methods alternative to traditional agricultural methods including greenhouse cultivation.

However, continuous application of these methods irrespective of the efficiency of production units causes them to become uneconomic and as a result, they can not be used. Hence, the efficiency of greenhouse units in the geography of Guilan province in the Islamic Republic of Iran has been measured here, the results of which indicate that only about 30% of the said units are efficient and that necessary attempts should be made to improve the efficiency of the rest of the greenhouses.

Also, for the research results to be applicable, optimum production input values for inefficient units have been computed and suggested as well.

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