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An analysis of the implementation of energy efficiency measures in the vegetable oil industry of Iran: a data envelopment analysis approach

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ABSTRACT

The vegetable oil industry is considered as one of the major industries contributing to energy consumption in Iran. Despite the increasing need to improve energy efficiency in this industry, previous studies show that energy-efficient technologies have not been applied in most plants and other energy efficiency measures have not yet been adopted. Accordingly, this paper addresses the implementation of energy efficiency measures in the vegetable oil industry. Using a data envelopment analysis (DEA), the relative efficiency of plants in the vegetable oil industry is compared at different stages of the implementation of energy efficiency measures. The most effective indices for improving energy efficiency were identified and a model was designed to implement energy efficiency measures in industrial plants. In the model, the implementation process consisted of 5 stages, each of which had its own inputs and outputs. A multi-stage DEA model was employed to evaluate the performance of vegetable oil plants at each individual stage as well as the aggregate efficiency of each plant. After estimating the total efficiency of all plants and evaluating performance at the individual stages for each plant, the plants with ideal conditions for implementing energy efficiency measures were identified. These plants can serve as a benchmark for other plants. Estimation of the average efficiency across plants at each stage indicated that the plants suffered from poor performance in the first and fourth stages. Therefore, the results of this study indicate a need to develop new strategies for improving energy efficiency at these two stages.

1. Introduction

The industrial sector is one of the main energy-consuming sectors in Iran, accounting for 23.8% of total energy consumption in 2010 (MOE, 2010). The food industry is one of the major consumers of energy and the vegetable oil industry is the second largest energy consumer among food industries. Levels of energy consumption in this industry were investigated by a number of energy companies in 2011. Natural gas consumption, fuel oil consumption, gas oil consumption and electricity consumption were 182,772,351 m^3, 32,045,138 L, 1,973,048 L and 229,844,131 kWh, respectively. The vegetable oil industry currently has 39 active plants throughout Iran, including oil refinery plants, oil extraction plants, and combined oil extraction and refineries. The nominal production capacity of oil by vegetable oil refinery plants is approximately 3463 kt/year, while the production capacity of oil extraction plants is approximately 550 kt/year of crude oil. The average thermal energy consumption intensity values for oil extraction and refinery plants (combined oil refinery and extraction); oil refinery plants with a gas plant system; oil refinery plants with an electrolysis gas system; and oil extraction plants are 13,691 MJ/t; 6359 MJ/t; 8101 MJ/t; and 6774 MJ/t, respectively, with corresponding average electrical energy consumption intensity values of 424 kWh/t; 116 kWh/t; 199 kWh/t; and 280 kWh/t, respectively. The average energy consumption intensity in Iran is higher than that in other countries, implying that the current level of energy consumption by the vegetable oil industry is undesirable (IFCO, 2012).

Therefore, it is essential to improve energy efficiency to ensure the survival and growth of this industry. Increased energy efficiency not only improves competitiveness by reducing costs but

Abbreviations: DEA, data envelopment analysis; DMU, decision-making unit.

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also reduces the adverse environmental effects associated with energy consumption, including air pollutants and greenhouse gas emissions. In spite of the need to improve industrial energy efficiency, studies show that cost-effective energy efficiency measures have not always been undertaken due to the various barriers preventing these measures (Rohdin et al., 2007). DeCanio (1993), Jaffe and Stavins (1994), and Sorrell et al. (2000) reported a gap between potential cost-effective energy efficiency measures and actual implemented measures, and explained this energy efficiency gap by citing a number of barriers to energy efficiency. DeCanio (1998) investigated the bureaucratic and organizational barriers to making profitable, energy-saving investments. He showed that, in addition to economic factors, organizational, institutional, and behavioral factors can affect firms' decisions to invest. UNEP (2006) discussed energy efficiency barriers in Asian industries as well as policy guidelines that address the perceived barriers. Rohdin and Thollander (2006), Rohdin et al. (2007), and Thollander and Ottosson (2008) performed studies on the barriers and drivers involved in energy efficiency implementation in Swedish industries. Economic, behavioral, and organizational barriers were found to be the three major barriers in the studies of Swedish industries. Sardianou (2008) investigated investment barriers to industrial energy efficiency in Greece. He found that an energy conservation framework would be more effective if the dissemination of industrial energy efficiency information was improved and investments were based on human capital. Fleiter et al. (2011) depicted barriers to adopting energy-efficient technologies using bottom-up models. Similar studies have been conducted to investigate energy efficiency barriers.

In the above mentioned studies, the barriers to energy efficiency were investigated, but neither energy efficiency measures in industrial plants nor the corresponding stages of implementation and effective indices of these measures were explained. It seems necessary to determine the effective indices of energy efficiency measures and then design the process of energy efficiency measure implementation based on these factors. Therefore, in this study, a multi-stage mathematical programming problem was built with regards to the process of energy efficiency measure implementation in industrial plants.

Data Envelopment Analysis (DEA), an evaluation technique based on mathematical programming, can systematically estimate the relative efficiency of industrial plants. DEA uses a model to evaluate the performance of a set of comparable decision-making units (DMUs). Each DMU is evaluated in terms of a set of inputs and outputs. Many researchers have endorsed DEA as being a useful method for estimating relative efficiency. Zhou et al. (2008) completed a literature review on the application of DEA in energy and environmental studies. Ramanathan (2000) used DEA to calculate energy efficiencies for modes of transportation in India. Ramanathan (2005) applied DEA in an analysis of energy consumption and carbon dioxide emissions in the Middle East and North Africa. Ramanathan (2006) used DEA to study the impacts of CO_2 emission and energy consumption on economic growth simultaneously. Pacudan and Guzman (2002) investigated the impact of energy efficiency policy on the production efficiency of the electricity distribution industry in the Philippines. They examined the technical efficiency of 15 electricity distribution utilities using a DEA approach. Hu and Kao (2007) employed a DEA approach to determine energy-saving targets for the Asian Pacific Economic Cooperation economies without reducing their potential maximum annual GDP. Semih and Soner (2007) analyzed energy use performance in a Turkish manufacturing sector and identified companies with high performance and low performance. K. Wang et al. (2012) applied several DEA-based models to evaluate the total-factor energy and emission performance of 30 Chinese regions within a joint production framework, considering desirable and undesirable outputs as well as separate energy and non-energy inputs. Shi et al. (2010) evaluated Chinese regional industrial energy efficiency using a DEA model. Sarica and Or (2007) used DEA to assess the efficiency of Turkish power plants. Wei et al. (2007) utilized DEA to examine energy efficiency changes in China's iron and steel sector. Wu et al. (2012) evaluated China's industrial energy efficiency and CO_2 emissions using DEA models. Z.H. Wang et al. (2012) also used a DEA method and framework for total factor-energy efficiency to establish an energy efficiency evaluation model. Blomberg et al. (2012) applied DEA to assess electricity efficiency improvement potential in Sweden's pulp and paper industry. In a paper provided by Zhou and Ang (2008) they discussed about undesirable output and presented several DEA-type linear programming models for measuring efficiency performance. Noted that the presented models treat different energy sources as different inputs and this makes changes possible in energy mix in evaluating energy efficiency. Also the proposed models are applied to measure the energy efficiency performances of 21 OECD countries. Also, Zhou et al. (2010) based on the same production framework with energy input and CO_2 emissions assessed carbon emission performance. Recently many investigations performed in DEA technique for introducing new models. As an instance Zhou et al. (2012a,b) extended the directional distance function into more general non-radial directional distance which can incorporate all the slacks in assessing energy and carbon performance. In addition to nonparametric DEA approach, a new trend is to use parametric stochastic frontier models to benchmark energy efficiency performance proposed by Zhou et al. (2012a,b).

The most important objective of this study was to measure and compare vegetable oil plants' relative efficiency at different stages of the implementation process of energy efficiency measures and to identify strategies for improving the stages that show low performance levels. Furthermore, the extent to which outputs should be changed to achieve efficient conditions in the poor performance stages was examined. The effective indices and the items needed to improve energy efficiency are described in the Material and Method section. These items were used to design a model for implementing energy efficiency measures in vegetable oil plants using a multi-stage DEA approach. In the Results and Discussion section, the implementation of the proposed model is described, and total efficiency and efficiency at each stage are analyzed individually. Finally, in the Conclusion section, recommended strategies for energy efficiency enhancement are discussed.

2. Data envelopment analysis

DEA models have been reviewed for assessing DMUs in two stages. This idea has been described by Kao (2009), and Fare et al. (2007). In a multi-stage model, the outputs from the first stage can be the inputs for the second stage. A two-stage DEA model is an extended version of the classical DEA model in which each DMU has two sequential sub-processes. The Stage 1 sub-process consumes inputs and produces outputs. The Stage 1 outputs are the inputs for the Stage 2 sub-process which, in turn, are used to produce the DMU outputs. This procedure is portrayed in Fig. 1.

The objective of efficiency assessment is to find strong or weak domains to make specific efforts to improve performance in low-efficiency systems. A production system that includes two

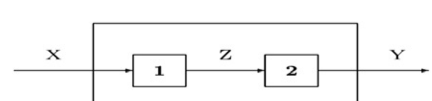

Fig. 1. A decision-making unit with two sub-processes. X denotes the input vector, Z and Y denote the intermediate and final output vectors.

processes allows for calculation of overall efficiency using a conventional DEA model as well as calculation of the efficiency of each sub-process, which allows for the identification of the source of inefficiencies in the system. More importantly, efficiency can be calculated separately for the whole process and for the two sub-processes. One outstanding feature of this model is that the two-stage model does not miss inefficiencies within a DMU. It is possible to distinguish between inefficiencies at each stage, enabling managers to identify inefficient stages in the production process. The model might be inefficient at either stage or at both stages, but the DMU will be efficient if both stages are efficient. However, managerial remedies for addressing inefficiency might be different within each individual stage. In the following equation, X is the input vector of m elements and Z is the output vector of f elements in the first sub-process. Considering both sub-processes and the whole DMU, Z is the vector of the intermediate product; therefore Z is the output for the first stage and the input for the second stage. P and V are weights related to inputs and outputs of the first stage, while j refers to number of DMUs. Also, Y stands for the final output (output of the second stage) of the DMU. Considering the sub-process of Stage 2 at DMU_o, U is a weight vector associated with the output of the second stage.

With models (1) and (2), it is possible to look inside at DMU_o and gain greater insight into the levels of inefficiency at each stage. Under the DEA assumptions, the intermediate product of the Stage 1 sub-process at DMU_o can increase to level Z_o and the output production of the Stage 2 sub-process can increase to level Y_o. Finally, the model is run to determine DMU_o's organizational efficiency, in which E_{1o}, E_{2o} and E_o are efficiency scores corresponding to the first stage, the second stage and the entire DMU, respectively.

E_o: The relative efficiency of the under evaluation unit (DMU_o)
y_{ro}: The rth output of the under evaluation unit (DMU_o)
x_{io}: The ith input of the under evaluation unit (DMU_o)
y_{rj}: The rth output of the jth unit
x_{ij}: The ith input of the jth unit
z_{lj}: The lth intermediate product for the jth unit
p_l: The weight of the ith intermediate product for the jth unit
u_r: The weight of the rth output for the jth unit
v_i: The weight of the ith input for the jth unit

$$\begin{aligned}
&\text{Max} \quad \frac{\sum_{r=1}^{s} u_r y_{ro}}{\sum_{i=1}^{m} v_i x_{io}} \\
&s.t. \quad E_{1j} = \frac{\sum_{l=1}^{f} p_l z_{lj}}{\sum_{i=1}^{m} v_i x_{ij}} \le 1, \quad j = 1,\dots,n, \\
&E_{2j} = \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{l=1}^{f} p_l z_{lj}} \le 1, \quad j = 1,\dots,n, \\
&E_j = \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \le 1, \quad j = 1,\dots,n, \\
&p_l \ge 0, \quad l = 1,\dots,f, \\
&u_r \ge 0, \quad r = 1,\dots,s, \\
&v_i \ge 0, \quad i = 1,\dots,m.
\end{aligned} \tag{1}$$

It is obvious that the third constraint is redundant, as it can be obtained from the first two constraints. It should be noted that efficiency of the whole process and the efficiencies of each of the two sub-processes are calculated independently. The concept of looking into a DMU and dividing it into sub-processes to better analyze a given scenario was first introduced by Kao and Hwang (2008). They mentioned that considering the DMU as a black box leads to inaccurate results. They also suggested that the two sub-processes and the whole process should be linked together to design a model which would describe a series of relationships. Clearly, overall efficiency is product of the efficiencies of two processes: $E_o = E_{1o} \times E_{2o}$, where E_o, E_{1o} and E_{2o} are optimal values of Model 1. The abovementioned models represent fractional programming that can easily be converted into the models' linear counterparts. As is evident from Model 1, the third fraction is redundant in terms of constraints. Thus, eliminating it leads to the linear form of the model as follows:

$$\begin{aligned}
&E_o^* = \text{Max} \quad \sum_{r=1}^{s} u_r y_{ro} \\
&s.t. \quad \sum_{i=1}^{m} v_i x_{io} = 1, \\
&\sum_{l=1}^{f} p_l z_{lj} - \sum_{i=1}^{m} v_i x_{ij} \le 0, \quad j = 1,\dots,n, \\
&\sum_{r=1}^{s} u_r y_{rj} - \sum_{l=1}^{f} p_l z_{lj} \le 0, \quad j = 1,\dots,n, \\
&p_l \ge 0, \quad l = 1,\dots,f, \\
&u_r \ge 0, \quad r = 1,\dots,s, \\
&v_i \ge 0, \quad i = 1,\dots,m.
\end{aligned} \tag{2}$$

3. Fuzzy background and defuzzification

The essential notions of fuzzy set theory that have been used in this paper are briefly reviewed here. Definitions and notations taken from Zimmermann (1986), and Zadeh (1965) are presented below:

Definition 1. Let X be a universal set; $\widehat{A}$is called a fuzzy set in X if $\widehat{A}$ is a set of ordered pairs:

$$\widehat{A} = \left\{ \left(X, \mu_{\widehat{A}}(X) \right) \middle| X \times X \right\} \tag{3}$$

Where $\mu_{\widehat{A}}(X)$ is a membership value of X in $\widehat{A}$.

Definition 2. A convex fuzzy set $\widehat{A}$ on R is a fuzzy number under the following conditions:

(a) Its membership function is piecewise continuous.
(b) There is only one X_o such that$\mu_{\widehat{A}}(X_o) = 1$.

Consider the following definition by Roychowdhury and Pedrycz (2001), and Runkler (1997):

Definition 3 (Center of gravity). In this method, defuzzification of fuzzy set $\widehat{A}$ is introduced as follows:

$$\text{Def}_{\text{COG}}\left(\widehat{A}\right) = \frac{\int_x xA(x)\text{d}x}{\int_x A(x)\text{d}x} \tag{4}$$

4. Materials and methods

Data collection is divided into four sections in this study, including: 1) a literature review to determine effective indices and items used improve industrial energy efficiency, 2) interviews with experts to describe a process for the implementation of energy efficiency measures in vegetable oil plants to design a model, and 3) design of questionnaires used to determine the values of each input

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and output in the process of implementing energy efficiency measures in the plants.

4.1. Effective indices for the improvement of energy efficiency

First, effective indices for improving energy efficiency were gathered from relevant studies. Then, this list of indices was presented to experts, including academics, industry owners and experts from organizations and institutions such as the Ministry of Energy, the Fuel Conservation Company and the Vegetable Oil Industry Association. After incorporating the experts' opinions, the most effective indices for improving energy efficiency were developed. These indices were divided into six main groups, presented in Table 1.

4.2. Model design

Several experts who had been actively involved in industry energy efficiency issues were interviewed after the efficiency indices and items for improvement in energy efficiency in the vegetable oil industry were defined. A process for implementing energy efficiency measures in the industry was defined based on the perspectives of these experts. The process was divided into five stages, each of which had its own inputs and outputs (Fig. 2).

In the first stage, the assigned budget for implementation of programs such as establishing and implementing energy management unit or improving the existing energy management system (X_1), performing energy auditing programs (X_2), and motivating subordinate personnel (X_3) were the inputs. The outputs were the implementation of the abovementioned program.

The outputs of the first stage were used as inputs for the second stage. In the second stage, the inputs were motivating subordinate personnel (Z_1), implementing an energy management unit or improving the existing energy management system (Z_2), and performing energy auditing programs (Z_3). These items could provide organizations with adequate information. In this stage, the intermediate inputs were the industry owners' trust in energy auditors (K_1), and the suitability of information forms (K_2). Outputs at this stage included all items associated with the organization members' awareness of cost-effective and energy-efficient technologies (L_1), high status of energy managers (L_2), designing systems for keeping records and information of energy consumption as well as providing documentation (L_3), energy managers' awareness of data collection methods (L_4), industry owners' awareness of the costs associated with completing information collection equipment (L_5), the existence of procedures for periodic energy data collection (L_6), symmetry of information associated with characteristics and performance of energy-efficient equipment (L_7), energy managers' awareness of areas of significant energy consumption and use (L_8), energy managers' awareness of opportunities to improve energy performance (L_9), and organization members' awareness of energy policy (L_{10}).

In the third stage, all items associated with information (the outputs of the second stage), which were also the inputs for the third stage, were items that could motivate the organization to make decisions towards investment in improvement of energy efficiency measures. It should be noted that other items involved in decisions would be used as intermediate inputs. These items included punitive policies, such as criteria for energy consumption (M_1); rational tariffs imposed on efficient energy technologies (M_2); adequate infrastructure facilities (M_3); high interaction levels of industry owners (M_4); reinstatement of competent managers (M_5); lack of concern about reducing the enterprise's competition in marketplace (M_6); managers' attention to cleaner production (M_7); industry owners' trust of executive managers (M_8); and industry owners' risk-taking (M_9). Making decisions to invest in the improvement of energy efficiency measures (W) was the output of the third stage and was also the input to the fourth stage.

In the fourth stage, the decisions made to invest in improving energy efficiency were implemented. It should be mentioned that the other items (intermediate inputs) involved in the implementation of these decisions included access to adequate capital (N_1), short-term finance processes (N_2), the existence of incentive policies (N_3), and flexibility to change (N_4). The implemented measures at this stage (the outputs) were the utilization of new technologies (O_1), the modification of existing equipment (O_2), upgrading and modernizing available technologies (O_3), measuring and controlling energy consumption (to implement measures such as internal audits of energy management systems) (O_4), the modification of working methods (to implement measures such as the modification of weekend time tables and coordination time of using equipments) (O_5), and other measures such as reducing the number of standby equipment units (O_6) (Zilahy, 2004). The fourth stage's outputs were the fifth stage's inputs. In the fifth stage, the organization achieves outputs by implementing the measures to improve energy efficiency. These outputs included reductions in cost (Y_1), energy consumption (Y_2) and environmental pollution (Y_3); reductions in depreciation, repairs and maintenance (Y_4); raising direct economic benefits (Y_5); and increasing energy productivity (Y_6); as well as increasing competitiveness (Y_7). It should also be noted that the energy efficiency measures may be implemented poorly in the fourth stage, such that the ultimate objective of reducing energy consumption is not achieved. In this case, the other items (the intermediate inputs) should be considered at this stage to better implement the measures and achieve the outputs. Generally, these items included the existence of ambitious people (T_1), possession of skills and managerial experience (T_2), personnel technical training (T_3), control of the executive managers by owners to coordinate the managers' benefits and behavior interactively (T_4), and funding for personnel education (T_5).

4.3. Identification of inputs and outputs in the process of implementation of energy efficiency measures in vegetable oil plants

A questionnaire including seven qualitative measures and items was designed to determine the effect of each item on improving energy efficiency. Fifteen vegetable oil plants received the questionnaire. Energy managers or the people involved in energy issues were chosen to fill out the questionnaire, as they had adequate knowledge about industrial processes and the factors inhibiting or promoting implementation of energy efficiency measures in the plants. The qualitative indices were then converted to quantitative indices according to the methods discussed in the defuzzification description, above. Because the data were fuzzy and were based on the fuzzy preliminaries previously mentioned, they were defuzzified and their crisp counterparts were used.

Generally, the input and output data presented here are linguistic variables consisting of words or sentences. Possible values for these variables are: extremely good, very good, good, average, poor, very poor and extremely poor. Each linguistic variable is indicated by a triangular fuzzy number between 0 and 1. The membership functions of the five levels of linguistic variables are (0. 0, 0. 0, 0.15), (0.20, 0.1, 0.1), (0.35, 0.1, 0.1), (0.50, 0.15, 0.1), (0.65, 0.1, 0.1), (0.8, 0.1, 0.1), and (1, 0.15, 0.0).

4.4. Identifying the importance of input and output items

A questionnaire including seven qualitative measures and items was designed to determine the effect of each item on energy efficiency. The questionnaire was presented to 21 experts involved in

Table 1
Effective indices for the improvement of energy efficiency.

Indices and sub-indices	Item	Descriptions
1. Economic		
1.1. Sufficient and accurate information	1.1.1. Being aware of cost-effective energy-efficient technologies (cost-effective energy efficiency investments) 1.1.2. Industry owners' awareness of the costs associated with completing data collection equipment	There are four general types of market failures: imperfect information, asymmetric information, incomplete markets and imperfect competition. Investments in energy-efficient technologies are affected by market failures that often hinder implementing cost-effective energy-efficient measures (Sorrell et al., 2000; Fleiter et al., 2011).
1.2. Symmetry of information	1.2.1. Symmetry of information associated with characteristics and performance of energy-efficient equipment among equipment producers and industry owners 1.2.2. Industry owners' trust for executive managers 1.2.3. Control of the executive managers by industry owners	Adverse selection is a form of asymmetric information, and symmetry of information between two parties involved in transaction provides power of accurate choice for equipment buyers (Rohdin et al., 2007). Asymmetric information between principal and agent resulted in basic long-term solutions for energy efficiency investment (DeCanio, 1993; Rohdin et al., 2007).
1.3. Access to capital	1.3.1. Access to adequate capital 1.3.2. Existence of adequate financing mechanisms (UNEP, 2006; Shi et al., 2008)	
1.4. Financing process	1.4.1. Easy and short-term financing process (UNEP, 2006)	
1.5. Education funding	1.5.1. Funding for personnel education (Sardianou, 2008)	
1.6. Risk-taking	1.6.1. Industry owners' risk-taking and their investment in new technologies without worrying about the risk of production disruptions (Thollander and Ottosson, 2008)	
2. Awareness and information		
2.1. Knowledge and technical expertise	2.1.1. Adequate knowledge and technical expertise in organizational levels) (Shi et al., 2008)	
2.2. Skills and experiences	2.2.1. The existence of skills and technical and managerial experiences in organizational levels (Nagesha and Balachandra, 2006)	
2.3. Training	2.3.1. Personnel technical training and creation of their training programs (Shi et al., 2008)	
2.4. Access to technical information	2.4.1. The existence of procedures for periodic energy data collection 2.4.2. Designing systems for keeping records and energy consumption information and for providing documentations (UNEP, 2006)	
2.5. Awareness	2.5.1. Energy managers' awareness of data collection methods 2.5.2. Organization members' awareness of energy policies and adopting them in their work activities 2.5.3. Energy managers' awareness of areas of eminent energy consumption and use 2.5.4. Energy managers' awareness of opportunities to improve energy performance (ISO 50001, 2011)	
3. Organizational		
3.1. Power	3.1.1. High status of energy managers within organization (Rohdin and Thollander, 2006)	
3.2. Organizational culture-building	3.2.1 Encouraging and motivating the subordinate personnel by top management	

(*continued on next page*)

Table 1 (*continued*)

Indices and sub-indices	Item	Descriptions
3.3. Higher priorities for cleaner production	3.3.1. Managers' attention to some issues like cleaner production, health and safety, and reducing production cost (Shi et al., 2008; UNEP, 2006)	
3. 4.Reinstatement policy in an organizational post	3.4.1. Reinstating competent managers in a post for a long time (DeCanio, 1993)	
3.5. Lack of concern about competition	3.5.1. Managers would not worry about reducing the enterprises' competition in the marketplace	If managers were aware that investment in energy efficiency would lead to increased productivity, they would not worry about the additional costs of the implementation of energy efficiency measures and adoption of cleaner production programs (Shi et al., 2008)
4. Behavioral		
4.1. Form of information	4.1.1. Suitability of information forms in energy reports	Existence of simple and clear information associated with particular conditions and specific plants problems in energy auditing reports in order to increase the possibility of information being accepted (Rohdin and Thollander, 2006)
4.2. Flexibility	4.2.1. Lack of managers' and personnel's resistance against changes (Sardianou, 2008)	
4.3. Trust	4.3.1. Industry owners' trust in energy auditors (Rohdin and Thollander, 2006)	
4.4. Values	4.4.1. The existence of ambitious people, especially at top management level (Rohdin et al., 2007)	
4.5. Work commitment	4.5.1. Lack of "others will do" syndrome (Naghesha and Balachandra, 2006)	
5. Structural and institutional		
5.1. Rationalization of prices	5.1.1. Reflecting environmental and social costs in fuel prices (IPCC, 2001)	
5.2. Infrastructure facilities	5.2.1. Adequate infrastructure facilities	Adequate infrastructure facilities to adopt new technologies in production process (Shi et al., 2008)
5.3. Interaction level	5.3.1. High interaction levels of industry owners	High interaction levels of industry owners with research and development institutions, technical colleges and associated institutions (Nagesha and Balachandra, 2006)
5.4. Standards setting and revising the process	5.4.1. Accelerating setting and revising the process and updating codes and standards (Hirst and Brown, 1990)	
5.5. End-use energy policies	5.5.1. Existence of end-use energy policies	Policies to address importance of investment in ultimate energy consumer sector and adopting innovative technologies for energy efficiency parallel to importance of investment in production, transmission and energy supply (Thollander, 2008)
6. Policy making		
6.1. Effective policies	6.1.1. Existence of laws, incentive policies and inhibitory mechanisms and penalties (UNEP, 2006)	
6.2. Pricing policies	6.2.1. Rational energy pricing policies and removal of energy subsidies (UNEP, 2006)	
6.3. Rational tariffs	6.3.1. Rationalization of customs tariffs	Rational tariffs imposed on imported goods (new and efficient energy technologies) to the country (IPCC, 2001)

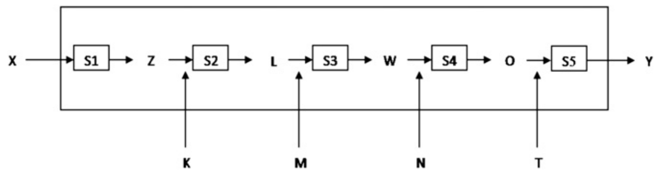

Fig. 2. A five-stage decision-making process for the implementation of energy efficiency measures in vegetable oil plants. Letters denote input/output vectors.

energy efficiency in the vegetable oil industry. The validity of questionnaire was assessed using SPSS software. The experts' comments about the items were multiplied by the qualitative measures, which were calculated to equal their crisps. The results indicated that average of the experts' comments identified a level of importance for every item. Using the outputs from the first stage and the experts' comments, the weight of each element of the input vector (explained above) and the importance of them were calculated. Thus, if the corresponding weights were c_1, c_2, and c_3, the following weight restrictions were obtained:

$$\begin{aligned} &c_2 - 1.0567\ c_3 \geq 0 \\ &c_3 - 1.0107\ c_1 \geq 0 \end{aligned} \tag{5}$$

Similar weight restrictions were also calculated for the other items.

4.5. Mathematical modeling

As explained before, to evaluate the efficiency of vegetable oil plants at different stages of the energy efficiency measure implementation process, it is essential to evaluate each stage individually and perform an aggregate evaluation for each individual plant. To this end, a multi-stage DEA model was used, whereby a DMU with five stages was developed. Based on the DEA literature, the following model was developed for evaluating the efficiency of vegetable oil plants:

$$\begin{aligned} &E_a = \text{Max}\ e^a \\ &s.t.\quad e^1 \leq 1, \\ &e^2 \leq 1, \\ &e^3 \leq 1, \\ &e^4 \leq 1, \\ &e^5 \leq 1, \\ &\text{V} \geq 1\varepsilon,\ \ \text{U} \geq 1\varepsilon,\ \text{C} \geq 1\varepsilon,\ \ \text{D} \geq 1\varepsilon, \\ &\text{F} \geq 1\varepsilon,\ \ \text{G} \geq 1\varepsilon,\ \ \text{P} \geq 1\varepsilon,\ \ \text{S} \geq 1\varepsilon, \\ &\text{L} \geq 1\varepsilon, \text{B} \geq 1\varepsilon. \end{aligned} \tag{6}$$

where each e^j (j = 1, 2, 3, 4, 5) stands for the efficiency of sub-processes, and e^a stands for aggregate efficiency, explained as follows:

$$e^1 = \frac{\text{C}^t\text{Z}}{\text{V}^t\text{X}},\ e^2 = \frac{\text{D}^t\text{L}}{\text{C}^t\text{Z} + \text{P}^t\text{K}},\ e^3 = \frac{\text{F}^t\text{W}}{\text{D}^t\text{L} + \text{S}^t\text{M}} \tag{7}$$

$$e^4 = \frac{\text{G}^t\text{O}}{\text{F}^t\text{W} + \text{L}^t\text{N}},\ e^5 = \frac{\text{U}^t\text{Y}}{\text{G}^t\text{O} + \text{B}^t\text{T}},\ e^a = \frac{\text{U}^t\text{Y}}{\text{V}^t\text{X} + \text{P}^t\text{K} + \text{S}^t\text{M} + \text{L}^t\text{N} + \text{B}^t\text{T}}$$

And o refers to the DMU under consideration ($o \in \{1, ..., n\}$). In the first stage, X and Z are input and output vectors, and V and C are the corresponding weight vectors. The same criteria applies to the second stage, in which Z and K are the inputs, L is the output vector, and C, P and D are the corresponding weight vectors. It should be noted that the output of the first stage is the input of the second stage, called an intermediate product. In the third stage, L and M are inputs and W is the output, and their corresponding weight vectors are D, S and F. For the fourth stage, W and N are inputs and O is the output, and the corresponding weight vectors are F, L and G. In the final (fifth) stage, O and T are inputs with corresponding weight vectors of G and B, respectively. In this stage, Y is the output and U is the weight vector. The model can be introduced as follows, where:

x_{io}: The ith input of the first sub-process of the unit under evaluation (DMU_o)
k_{ho}: The hth input of the second sub-process of the unit under evaluation (DMU_o)
m_{ko}: The kth input of the third sub-process of the unit under evaluation (DMU_o)
n_{so}: The sth input of the fourth sub-process of the unit under evaluation (DMU_o)
t_{xo}: The xth input of the fifth sub-process of the unit under evaluation (DMU_o)
y_{ro}: The rth output of the fifth sub-process of the unit under evaluation (DMU_o)
x_{ij}: The ith input of the first sub-process of the jth unit
z_{aj}: The ath intermediate product of the first sub-process of jth unit
k_{hj}: The hth input of the second sub-process of the jth unit
l_{sj}: The sth intermediate product of the second sub stage of the jth unit
m_{kj}: The kth input of the third sub-process of the jth unit
$w_{\bar{j}j}$: The $\bar{j}^{\text{th}}$ intermediate product of the third sub-process of the jth unit
n_{ej}: The eth input of the fourth sub-process of the jth unit
o_{qj}: The qth intermediate product of the fourth sub-process of the jth unit
t_{xj}: The xth input of the fifth sub-process of the jth unit
y_{rj}: The rth output of the fifth sub-process of the jth unit

$$\begin{aligned} &e_a = \text{Max} \sum_{r=1}^{s} u_r y_{ro} \\ &s.t.\ \sum_i v_i x_{io} + \sum_h p_h k_{ho} + \sum_e l_e n_{eo} + \sum_x b_x t_{xo} + \sum_k s_k m_{ko} = 1, \\ &\sum_a c_a z_{aj} - \sum_i v_i x_{ij} \leq 0, \quad j = 1, \ldots, n, \\ &\sum_s d_s l_{sj} - \sum_a c_a z_{aj} - \sum_h p_h k_{hj} \leq 0, \quad j = 1, \ldots, n, \\ &\sum_{\bar{j}} f_{\bar{j}} w_{\bar{j}} j - \sum_s d_s l_{sj} - \sum_k s_k m_{kj} \leq 0, \quad j = 1, \ldots, n, \\ &\sum_q g_j o_{qj} - \sum_j f_{\bar{j}} w_{\bar{j}j} - \sum_e l_e n_{ej} \leq 0, \quad j = 1, \ldots, n, \\ &\sum_r u_r y_{rj} - \sum_q g_j o_{qj} - \sum_x b_x t_{xj} \leq 0, \quad j = 1, \ldots, n, \\ &\text{V} \geq 1\varepsilon,\ \ \text{U} \geq 1\varepsilon,\ \ \text{C} \geq 1\varepsilon,\ \ \text{D} \geq 1\varepsilon, \\ &\text{F} \geq 1\varepsilon,\ \ \text{G} \geq 1\varepsilon,\ \ \text{P} \geq 1\varepsilon,\ \ \text{S} \geq 1\varepsilon, \\ &\text{L} \geq 1\varepsilon,\ \ \text{B} \geq 1\varepsilon. \end{aligned} \tag{8}$$

This model was demonstrated to be bounded and feasible. Consistent with the methods discussed above. It can also be concluded that while an optimal solution of Model 4 is at hand,

$$e^a = e^1 \cdot e^2 \cdot e^3 \cdot e^4 \cdot e^5 \tag{9}$$

Model 8 is defined as for evaluating covering the system as explained above. This model is built for a five-stage DMU with inputs and outputs for each stage. One of the key features of the model, which was designed for the previously mentioned applications, is its simplicity. To achieve more reliable results, experts' opinions should be incorporated into the evaluation of the model. It should be mentioned that all of the data, including the inputs, outputs and qualitative indices, are linguistic variables. According to the above mentioned discussion preliminaries for fuzzy background, the data should be defuzzified so that the corresponding crisp data can be obtained and utilized in the model. As described in the DEA literature, weight restrictions are of great importance. Therefore, experts' opinions have been added to the model to obtain more valid results. Some of the experts' opinions have been mentioned here, while others have been omitted for simplicity. The omitted weight restrictions can be calculated and added to abovementioned model as discussed previously.

5. Results and discussion

5.1. Investigating plant efficiency and performance at each stage

Total efficiency for each plant and efficiency at each of the 5 stages were calculated using DEA technique by running Model 8 and inputting the data into GAMS software. The plants were divided into several categories at each stage based a ranking of the efficiency values from highest to lowest (Table 3). Total efficiency for the plants ranged between 0 and 1. A proposed classification for the level of efficiency, ranging from 0 to 1, is presented in Table 2. Based on the classification in Table 2, the efficiency values have been placed in the corresponding range to evaluate each plant's efficiency.

In Stage 1, Plants No. 1, 7, and 2 are in very good condition according to the proposed classification. These plants show high performance levels in the use of funds to implement programs that established energy management units, improved existing energy management systems, established energy audits, or motivated subordinate personnel. The managers were able to match the outputs (make decisions about the deployment of energy management units, energy auditing programs and motivation programs) and allocate funding to implement these programs well. At the first stage, these plants are a good benchmark for other plants. Plants No. 10, 13, and 6 are in average condition compared to the other plants. It is obvious that the management at these plants is relatively weak and the managers are unable to thoroughly match the inputs and outputs. Plants No. 3, 4, 5, 8, 9, 11, 12, 14, and 15 are in poor condition compared to the other plants. According to the efficiency values, the managers of these plants have performed 48%, 46%, 42%, 42%, 36%, 34%, 30%, 27%, and 27% of their potential, indicating a poor performance and an inability by management to match inputs and outputs.

In Stage 2, items such as energy management establishment, implementing energy auditing programs and motivating subordinate personnel with intermediate inputs (items associated with box K) lead to the production of outputs (items associated with box L). According to the proposed classification, Plants No. 3, 6, 7, 11, 14, and 15 are in very good condition in this stage compared to the other plants. These plants show the highest performance in converting inputs to outputs. In accordance with implementation of the mentioned programs, the levels of awareness and organizational information are high, and the managers were able to match the inputs and outputs. Plants No. 1, 2, 8, 10, and 12 are in good condition. These plants show a high performance level in converting inputs and have been successful in match inputs with outputs. However, Plants No. 4, 5, 9, and 13 are in average condition.

Table 2
Proposed levels for classifying efficiency from 0 to 1.

Range	0–0.2	0.2–0.5	0.5–0.7	0.7–0.85	0.85–1
Situation	Very poor	Poor	Average	Good	Very good

According to the efficiency values, the managers have performed approximately 68%, 68%, 63%, and 57% of their potential, and have failed to thoroughly match inputs with outputs.

In Stage 3, Plants No. 5, 12, 13, and 15 are in very good condition comparatively, according to the proposed classification. These plants have been successful in converting inputs (all items associated with box L) and other items affecting decisions (all items associated with box M) into outputs. In fact, the managers have been able to match decision-making to invest in energy efficiency measures with effective items to make decisions. Plants No. 1, 2, 3, 4, 6, 7, 8, 10, and 11 are in good condition. These plants have been successful in match inputs with outputs, implying that the management has been successful in converting these inputs to outputs. However, Plants No. 14, and 19 are in average condition because the managers have not been able to fully match inputs with outputs and have performed 59% and 55% of their potential for Plants No. 14, and 19, respectively.

In Stage 4, Plants No. 2, 5, 7, 9, and 11 are in very good condition. These plants have been able to implement their decisions and invest in energy efficiency improvement measures. The managers have been successful in matching inputs (items associated with boxes W and N) and outputs (items associated with box O). Plant No. 10 is in good condition. This plant shows a high performance level in converting inputs to outputs, while implementing measures in accordance with past decisions. In contrast, Plants No. 1, 6, 8, 12, and 15 are in poor condition. According to the efficiency values, the managers at these plants have only been able to show 49%, 49%, 40%, 33% and 21% of their potential. The managers have not been successful in matching inputs with outputs and bringing about a desirable performance. Plants No. 3, 4, 13, and 14 are in very poor condition. At these plants, the managers have not been able to match outputs with inputs in any way. According to the efficiency values, these managers have performed 12%, 5%, 3% and 0.6% of their potential.

In Stage 5, Plants No. 1, 2, 3, 6, 8, 7, 11, 13, and 15 are in very good condition. At these plants, the managers exhibited a high performance level by implementing energy efficiency improvement measures (items associated with box O), aided by certain effective factors that allowed them to better implement the measures (items associated with box T), and they achieved outputs that included reducing energy consumption, reducing costs, reducing environmental pollutants, raising direct economic benefits, and meeting expectations for higher productivity and competition. Plants No. 9, 10, 12, and 14 are in good condition. These plants show good performance in converting inputs to outputs and have been successful in matching inputs with outputs. Plants No. 4, and 5 are in average condition. At these plants, the managers have shown approximately 66% of their potential, and failed to completely match outputs with inputs.

5.2. Total efficiency of plants

The aggregate efficiency of the plants is shown in Table 3. According to the proposed classification, Plants No. 2, and 7 are in very good condition compared to the other plants. The managers have brought about high performance in aggregate processes associated with implementing energy efficiency measures and have managed to fully match inputs with outputs. For example, the management success at Plant No. 2 was due to the establishment of an active energy management unit as well as the implementation of energy auditing programs. The organization was provided with adequate information about cost-effective solutions and energy efficiency measures through a comprehensive energy auditing program. Solutions for increasing energy efficiency in this plant include establishing simultaneous production systems, using automatic

Table 3
Total efficiency values, efficiency values and average efficiency at each stage for vegetable oil plants.

Stage 1		Stage 2		Stage 3		Stage 4		Stage 5		Total efficiency	
Plant no.	Efficiency	Plant no.	Efficiency	Plant no.	Efficiency	Plant no.	Efficiency	Plant no.	Efficiency	Plant no.	Efficiency
1	1	6	1	12	1	2	1	1	1	7	0.943
7	1	14	1	5	0.876	5	1	2	1	2	0.889
2	0.891	3	0.981	15	0.858	7	1	6	1	1	0.778
10	0.571	7	0.977	13	0.853	9	1	7	1	11	0.776
13	0.571	15	0.891	3	0.790	11	1	11	1	6	0.755
6	0.505	11	0.858	6	0.774	10	0.806	13	1	10	0.748
14	0.486	1	0.812	2	0.764	15	0.497	3	0.974	5	0.713
3	0.461	2	0.791	11	0.748	6	0.497	8	0.970	15	0.701
9	0.4290	10	0.783	1	0.745	8	0.402	15	0.961	9	0.676
4	0.424	12	0.721	7	0.740	1	0.335	10	0.846	3	0.665
8	0.361	8	0.716	10	0.733	12	0.220	14	0.845	8	0.636
5	0.341	5	0.686	8	0.732	3	0.121	12	0.823	13	0.611
15	0.300	9	0.686	4	0.714	13	0.056	9	0.711	12	0.608
12	0.276	4	0.633	14	0.595	4	0.039	5	0.662	14	0.587
11	0.272	13	0.577	9	0.555	14	0.007	4	0.661	4	0.494
Average efficiency of all plants in each stage											
0.528		0.807		0.765		0.532		0.897			

control systems for boiler combustion control (also known as the air/fuel ratio control strategy), using monitoring equipment, implementing automatic controls of energy, and utilizing speed-controlling super power motors. The manager held a high position in this plant, and most of the departments, including production, quality control, and administration, were effectively cooperated with him. The energy manager's power and credibility were the main reason that energy efficiency was considered a higher priority in the organization because the manager realized which facilities should be employed for system monitoring and data collection and which facilities should be used for resolving information deficiencies. Other useful measures implemented at the plant included the daily collection of energy consumption information by the energy management unit and the documentation of information and measures by the energy manager. Notably, technical education of personnel in the fields of energy, production processes and equipment was found to be important. The motivation of subordinate personnel was another important measure implemented at this plant. Moreover, the organizational managers were capable of encouraging their personnel in energy efficiency areas. The plant was successful in implementing energy efficiency improvement measures due to increases in the knowledge and motivation of both managers and personnel. Therefore, these plants can serve as good benchmarks for other plants. Plants No. 1, 5, 6, 10, 11, and 15 are in good condition compared to the other plants. These plants enjoy high performance in converting inputs to outputs and have been successful in matching outputs with inputs. These units can reach good condition if following plants No. 2, and 7 as benchmark. Plants No. 3, 8, 9, 12, 13, and 14 are in average condition. In these plants, the managers have been able to show 67%, 66%, 63%, 61%, 60% and 58% of their potential, and have failed to fully match inputs with outputs. Plant No. 4 is in poor condition, indicating that the management has failed to match inputs with outputs in this plant. Considering the total performance in this plant, the managers have been able to show 49% of their potential, with the final result being poor performance.

5.3. *The average efficiency of plants for each stage*

The average efficiency of plants calculated for each stage is presented in Table 3. In Stage 5, Stages 2 and 3, and Stages 4 and 1, the average efficiency of plants is considered to be very good condition, good condition and average condition, respectively. The units under evaluation are known to have high performance in the fifth, second and third stages. In the fourth stage, the DMUs have not been able to implement decisions to invest in energy efficiency improvement measures. The managers have not been able to match inputs with outputs in this stage. Moreover, in the first stage, the plants have not shown high efficiency in using budgets to implement energy management units, perform energy auditing and increase motivation. Generally, the managers of these plants have not been able to fully match the outputs and efficiently manage their budgets.

5.4. *Determining ideal conditions for outputs in the first and fourth stages*

It is essential to develop new strategies for the first and fourth stages because the average efficiency across all plants for these stages was of average condition. The extent to which outputs must be changed to achieve desirable efficiency conditions should be determined. In the fourth stage, Plants No. 1, 3, 4, 6, 8, 12, 13, 14, and 15 are in poor or very poor condition. The ideal conditions for all outputs were determined for each of the plants. The results from plants No. 14, and 15 are presented here as an example. Plant No. 15 should adopt new technologies (O_1) to achieve the appropriate conditions and to increase outputs from 2% to 4%. The values of the other outputs (O_2 to O_6) are 2%, 0.5%, 2%, 0.5% and 0.5%, which should be increased to 4%, 1%, 4%, 1% and 1%, respectively, to achieve ideal conditions. In Plant No. 14, in which is in very poor condition, the output values of 0.1%, 0.1%, 0.15%, 0.05% and 0.05% should be increased to 16%, 16%, 16%, 8% and 8%, respectively, to achieve ideal conditions. In the first stage, Plants No. 3, 4, 5, 6, 8, 9, 10, 11, 12, 13, 14, and 15 show average or poor conditions. The desirable condition for outputs for these plants in the first stage was calculated, and the results for Plant No. 14 are presented here. Plant No. 14 should increase motivation among subordinate personnel (Z_1) to achieve the desirable conditions and increase outputs from 0.35 to 0.72. In other words, this output should be shifted from a low value to a high value so that the management can raise the current conditions (which are undesirable) to more desirable conditions by adopting appropriate strategies. The output values of Z_2 and Z_3 are 0.8 and 0.2, respectively. These outputs should be increased to 1 and 0.4 for Z_2 and Z_3, respectively, to achieve the desirable conditions.

6. Conclusion

The proposed model was used to measure plant performance in five stages. The performance of each plant was measured individually at each stage. This method allowed for the identification of plants qualified to serve as benchmarks at each stage, as well as the identification of plants in need of improvement. The evaluation of the overall performance of the plants demonstrated that at Plants No. 2 and 7, managers have been able to successfully implement measures to improve energy efficiency.

The plants showed high performance levels in the second, third, and fifth stages; thereby the DMUs did not identify new strategies by examining the average efficiency of the plants for each stage. However, the plants did not show high levels of performance in the first and fourth stages, suggesting that these stages are flawed and that there is a need to develop new strategies. To be effective, the large-scale strategies of policy makers should focus first on the fourth stage and then on the first stage. The strategies needed to improve energy efficiency at these two stages are:

- Mandatory policies such as the obligatory implementation of energy auditing programs and the establishment of energy management systems in plants.
- Subsidies to establish energy management systems and implement energy auditing programs in plants.
- Voluntary programs to improve energy efficiency and decrease environmental pollutants (including voluntary agreements between government and industries).
- Education on energy management systems, audits for cleaner production, technology requirements and feasibility studies.
- Sector-specific demonstration projects and increased dissemination of information with the objectives of motivating managers to address energy efficiency improvement and making managers more aware of energy-efficient technologies.
- Subsidies (direct investments, low interest loans and tax rebates) for implementing energy efficiency measures that can be obtained quickly by minimizing bureaucratic processes.
- Inform plants about institutions and existing financial packages.
- Increase personnel knowledge through educational programs using educational pamphlets, CDs, notifications, and advertisements.

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