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Energy Resources Consumption Performance in Iranian Manufacturing Industries Using Cost/Revenue Efficiency Model

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ABSTRACT

Industries are one of the main sources of pollution in the world. Besides, the levels of energy resources consumption including water, electricity, and fossil fuel are very different among industries. On the other hand, Iranian government pays a large amount of energy subsidy to manufacturing units. Because of it, the government wants to know which of manufacturing industries are efficient, produce less environmental pollutions, and hence, must be supported. Besides, manufacturing industries are classified into various groups. In this paper, the conventional data envelopment analysis (DEA) model has been extended to multi-group state for evaluating manufacturing systems. The main feature of the proposed model is that it takes into consideration inputs/outputs prices (cost/revenue). In the other words, we propose a linear multi-group cost/revenue efficiency model. The data of 59 Iranian manufacturing industries are grouped under 23 classes to demonstrate the model. The inputs are energy resources such as the amount of fossil fuel, water and electricity consumption as well as a non-energy resources such as the number of employees. The results show that the efficiency scores and energy consumption performance are greatly changed when each industry is evaluated in its own group.

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1. INTRODUCTION

According to the World Bank's report, Iran is one of the largest economies in the Middle East having a large resource of oil, gas, and marine. These resources cause expansion of related industries and lead to a strong potential to extend manufacturing industries. Iran has various manufacturing plants and mostly, the principal parts have governmental structure. Besides, the manufacturing units receive a large amount of subsidy and therefore, most of them do not incline to improve their performance. In this paper, a new model based on the resources prices is proposed for evaluating the performance of manufacturing systems and their sub-branches according to the International Standard Industrial Classification (ISIC) codes (Revision 3).

There are various methodologies for evaluating the performance of decision-making units (DMUs) including parametric versus non-parametric. Parametric methodologies are often based on the statistical method and use declared parameters to estimate production (efficiency) frontier. On the other hand, non-parametric methodologies do not require assuming a particular functional form or shape for the production (efficiency) frontier. Data envelopment analysis (DEA) is the well-known non-parametric mathematical programming methodology widely used for measuring the performance.

Charnes et al. introduced DEA and Banker et al. extended it by considering variable return to scale assumption [1, 2]. Since DEA was introduced, researchers have studied both theoretical and practical aspects. DEA has been applied in various areas such as material selection [3], industries [4], supply chain ([5-7], healthcare systems [8, 9], energy systems [10-12], financial institutes and bank branches [13, 14] and quality control [15].

Energy evaluation in manufacturing systems is one of the main practical areas in DEA. Onut and Soner

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applied DEA for measuring performance of energy in Turkish manufacturing sectors [16]. Because energy cost is a large portion of the production cost, they essentially took energy costs into consideration. Liu used an integrated approach based on DEA/AR for selecting flexible manufacturing systems (FMS) [17]. The model evaluates the performance of FMS when the inputs/outputs are as fuzzy data. Sueyoshi and Goto used DEA for comparing disposability among industry units [18]. For this purpose, they considered two groups of Japanese firms including electric power industry and manufacturing industries. Egilmez et al. integrated Life Cycle Assessment (LCA) and DEA to analyze the sustainability of manufacturing sectors in the United States [19]. Their proposed approach was able to discern among eco-efficient and eco-inefficient units. Goto et al. used DEA for evaluating operational and environmental efficiencies on Japanese regional industries [20]. They assessed industries according to two groups of outputs including desirable and undesirable outputs. They concluded that Japanese industries needed to reduce the greenhouse gas emissions and air pollution as undesirable outputs by investing in technology innovation. Ren et al. evaluated the life cycle energy efficiency of six biofuels in China using DEA [21]. Egilmez and Park utilized DEA for assessing eco-efficiency by considering transportation related carbon, energy and water footprint analysis of U.S. manufacturing [22]. Several papers have been published in this area that we suffice to mention a few of them.

On the other hand, there are few studies in evaluating DMUs with considering subgroups. In earlier studies of group evaluation, Cook and Green introduced the hierarchical property of the unit structure [11]. They proposed the methodology for measuring efficiency at two levels of power plants. Camanho and Dyson proposed a within-group evaluation model based on Malmquiest index for measuring performance of units in four different regions [23]. The applicability of the proposed models was illustrated by the assessment of bank branches' performance. Afterwards, Cook and Zhu proposed a within- group model for evaluating power plants [24]. They supposed that DMUs might be put into several groups. Their proposed model was a nonlinear min-max model. For solving this model, they treated one of the variables as a parameter and then solved the reduced model for obtaining optimal solution. The nature of model caused the use of this model restricted. Also, this approach was used by Jahangoshai-Rezaee and Karimdadi to evaluate hospitals in different provinces in Iran [25].

Bagherzadeh Valami used another form of group evaluation to evaluate the performance of commercial banks. In the case study, the geometric mean of the output distance function of DMUs from considered group was used [26]. Thanassoulis et al. developed an index based on Malmquiest productivity index for comparing the productivity of groups when input prices are available [27].

In this paper, a revised model of group evaluation is introduced. Linearity and inputs/outputs prices are main characteristics of the proposed model. In the other words, we propose a multi-group linear cost/revenue efficiency model. In the proposed approach, decision-making units are classified into various groups and each group is equivalent to an ISIC code (Industry sector). It causes that, units in each category (Industry sector) be evaluated in homogenous environment. For this purpose, the conventional DEA model has been developed for this structure. The main feature of the proposed model is that it takes into consideration the industry classification. On the other hand, it causes units to be evaluated in homogenous environment. It is obviously closer to reality in evaluation of industrial units' performance. Briefly, the main contribution of this paper is evaluation of industrial units in multi-group state that each group is equivalent to an ISIC code with considering prices of inputs/outputs.

The rest of this paper is organized as follows: Section 2 presents the conventional DEA versus the cost and revenue efficiency models. In addition, the models will extend in multi-group according to cost/revenue efficiency. Section 3 provides a case study on multi-group cost efficiency of Iranian manufacturing. Furthermore, the results of the case study are presented in this section. Finally, the summary and conclusion are given in Section 4.

2. CONVENTIONAL DEA V.S. COST/REVENUE DEA MODELS IN MULTI-GROUPS

Data envelopment analysis has been applied in various areas as mentioned in previous section. The conventional model of DEA that has been introduced by Charnes et al. for evaluating the Texas' schools is expressed as follows [2]. Suppose, we have n DMUs and each DMU_j ($j=1 \dots n$) produces s outputs y_{rj} ($r=1 \dots s$) by utilizing m inputs x_{ij} ($i=1 \dots m$). Therefore, we have:

$$
\begin{aligned}
& max\ \frac{\sum_{r=1}^{s} u_r y_{ro}}{\sum_{i=1}^{m} v_i x_{io}} \\
& \text{s.t.}\ \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \le 1, \quad j=1,\dots,n \\
& u_r, v_i > 0, \quad i=1,\dots,m,\ r=1,\dots,s
\end{aligned}
\tag{1}
$$

In the real world cases, DMUs are usually classified into several groups. It is important that managers may evaluate DMUs within own group as well as among groups. For precision evaluation, it is necessary to consider inputs/outputs prices.

This paper mentions Cook and Zhu and develops it for cost/revenue efficiency model [24]. For this purpose, the principal concepts of cost and revenue efficiency models are provided. In this paper, we propose the multi-group DEA models with considering inputs/outputs prices.

2. 1. Cost and Revenue Efficiency Model In this section, the basic models of cost/revenue efficiency based on DEA models with preference structure are presented. Let p_i (i=1,…,) denote the *i*th input price for DMU$_o$ and $\hat{x}_{io}$ represent the *i*th input. The goal is to minimize the cost according to the related prices and therefore, the cost efficiency model is expressed as follows:

$$\begin{aligned} Min \quad & \sum_{i=1}^{m} p_i \hat{x}_{io} \\ s.t. \quad & \sum_{j=1}^{n} \lambda_j x_{ij} \le \hat{x}_{io} \quad , i=1,...,m \\ & \sum_{j=1}^{n} \lambda_j y_{rj} \ge y_{ro} \quad , r=1,...,s \\ & \lambda_j, \hat{x}_{io} \ge 0 \end{aligned} \tag{2}$$

The dual of model (2) is as follows:

$$\begin{aligned} Max \quad & \sum_{r=1}^{s} u_r y_{ro} \\ s.t. \quad & \sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \le 0 \quad j=1,...,n \\ & 0 \le v_i \le p_i \qquad i=1,...,m \\ & u_r \ge 0 \end{aligned} \tag{3}$$

Regarding models (2 and 3), there are relationships between $\hat{x}_{io}$ and v_i . If $\hat{x}_{io} > 0$ in model (2), $v_i = p_i$ in model (3). Therefore, v_i can be considered as *i*th input price. The equivalent of above models for the revenue efficiency models are:

$$\begin{aligned} Max \quad & \sum_{r=1}^{m} p_r \hat{y}_{ro} \\ s.t. \quad & \sum_{j=1}^{n} \lambda_j x_{ij} \le x_{io} \quad , i=1,...,m \\ & \sum_{j=1}^{n} \lambda_j y_{rj} \ge \hat{y}_{ro} \quad , r=1,...,s \\ & \lambda_j, \hat{y}_{ro} \ge 0 \end{aligned} \tag{4}$$

$$\begin{aligned} Min \quad & \sum_{i=1}^{m} v_i x_{ro} \\ s.t. \quad & \sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \le 0 \quad j=1,...,n \\ & 0 \le u_r \le p_i \qquad r=1,...,s \\ & v_i \ge 0 \end{aligned} \tag{5}$$

Similar to the interpretation of the cost efficiency model, $\hat{y}_{ro} > 0$ in model (4) results in $u_r = p_r$ in model (5). Hence, u_r will be *r*th output price. Accordingly, the relative cost and revenue efficiencies for DMU$_o$ are defined as:

$$\text{Cost effiecency} = \frac{\sum_{i=1}^{m} p_i \hat{x}_{io}^*}{\sum_{i=1}^{m} p_i x_{io}}, \tag{6}$$

$$\text{Revenue effiecency} = \frac{\sum_{r=1}^{s} p_i y_{ro}}{\sum_{r=1}^{s} p_i \hat{y}_{ro}^*} \tag{7}$$

2. 2. Proposed Multi-group Model Now, suppose that DMUs are classified into *k* groups. Let J_k (k=1… K) denote the *kth* group using *m* inputs (x_{ij}) to produce *s* outputs (y_{rj}). Optimal cost (revenue) efficiency scores for each DMU in each group are evaluated by model (2) and Equation (6) (or model (4) and Equation (7)). Denote θ_{j_k} as the efficiency scores for *jth* member of *kth* group. These scores are regarded as ideal efficiency points and are calculated using all DMUs in evaluation, not considering groups. But the nature and characteristics of DMUs differ in various groups (especially in our case study mentioned in the next section). Hence, a way must be found to restrict DMUs' weights in each group. In this paper, we propose a common weight model to evaluate each DMU among its own group as well as among all DMUs. This model, contrary to Cook and Zhu model, is a linear model based on cost/revenue efficiency [24]. Cook and Zhu proposed a nonlinear model based on common weights and applied two algorithms called Dinkelbach's algorithm and consecutive interval search [24, 28]. These algorithms give rise to approximate inaccurate solutions. Hereinafter, we consider specific prices for each input or output although some prices have equal values. These prices are used to develop the multi-group efficiency model based on cost/revenue models. Denote θ_{j_k} as the cost (revenue) efficiency score for each member of *k*th group that is calculated by model (2) or model (4). Also, let J_{k_o} denote the group under evaluation. In this case, for the set of DMUs ($j_k \in J_{k_o}$), we consider the goals for each DMU as follows:

$$\frac{\sum_{i=1}^{m} p_i \hat{x}_{ij_k}}{\sum_{i=1}^{m} p_i x_{ij_k}} = \theta_{j_k}, \quad j_k \in J_{k_o} \tag{8}$$

This equation attempts to hold the original efficiency score for each member of *kth* group that is impossible. Therefore, it is supposed that the original efficiency scores (θ_{j_k}) are the upper bounds for the left side of Equation (8). In the other words, we have:

$$\frac{\sum_{i=1}^{m} p_i \hat{x}_{ij_k}}{\sum_{i=1}^{m} p_i x_{ij_k}} \leq \theta_{j_k}, \quad j_k \in J_{k_o} \tag{9}$$

The objective would be to seek a set of $\hat{x}_{ij_k}$ for which, the total achievement of the goals in Equation (8) is minimized. Therefore, a set of variables $\{\gamma_{j_k}\}$ is added to Equation (9). By using ℓ_1 norm, model (10) is developed to calculate the optimal inputs for each group. Hence, the group efficiency model is expressed as follows:

$$\begin{aligned} Min \quad & \sum_{j_k \in J_{k_o}} \gamma_{j_k} \\ s.t. \quad & \frac{\sum_{i=1}^{m} p_i \hat{x}_{ij_k}}{\sum_{i=1}^{m} p_i x_{ij_k}} + \gamma_{j_k} = \theta_{j_k}, \quad j_k \in J_{k_o} \\ & \sum_{j=1}^{n} \lambda_j x_{ij} \leq \hat{x}_{io} \quad , i = 1,...,m \\ & \sum_{j=1}^{n} \lambda_j y_{rj} \geq y_{ro} \quad , r = 1,...,s \\ & \lambda_j, \hat{x}_{io} \geq 0 \end{aligned} \tag{10}$$

Models (10 and 11) are run for each DMU in each group. $\hat{x}_{io}$ and y_{ro} are referred to DMU under evaluation in each group. Model (10) is converted to model (11) as follows:

$$\begin{aligned} Min \quad & \sum_{j_k \in J_{k_o}} \gamma_{j_k} \\ s.t. \quad & \\ & \sum_{i=1}^{m} p_i \hat{x}_{ij_k} + (\gamma_{j_k} - \theta_{j_k}) \sum_{i=1}^{m} p_i x_{ij_k} = 0, \; j_k \in J_{k_o} \\ & \sum_{j=1}^{n} \lambda_j x_{ij} \leq \hat{x}_{io} \quad , i = 1,...,m \\ & \sum_{j=1}^{n} \lambda_j y_{rj} \geq y_{ro} \quad , r = 1,...,s \\ & \lambda_j, \hat{x}_{io} \geq 0 \end{aligned} \tag{11}$$

This model is a linear programming model contrary to Cook and Zhu model [24]. This makes the model become easily solvable and obtains optimal solutions without using any extra algorithms. After obtaining $\hat{x}_{io}$, Equation (6) is used for calculating new cost efficiency score for DMU_o. The equivalent of the multi-group cost efficiency model is the multi-group revenue efficiency model for output-oriented revenue efficiency. Therefore, we will rewrite Equation (8) as follows:

$$\frac{1}{\theta_{j_k}} = \frac{\sum_{r=1}^{s} p_r \hat{y}_{ro}}{\sum_{r=1}^{s} p_r y_{ro}}, \quad j_k \in J_{k_o} \tag{12}$$

Similar to Equation (8), this equation attempts to hold the original efficiency score for each member of *kth* group that is impossible, too. Therefore, we have:

$$\frac{\sum_{r=1}^{s} p_r \hat{y}_{ro}}{\sum_{r=1}^{s} p_r y_{ro}} \geq \frac{1}{\theta_{j_k}}, \quad j_k \in J_{k_o} \tag{13}$$

Similarly, the objective would be to seek a set of $\hat{y}_{ro}$ for which the total under-achievement of the goals in Equation (12) is minimized. Therefore, the group efficiency model for output-oriented revenue efficiency is expressed as follows:

$$\begin{aligned} Min \quad & \sum_{j_k \in J_{k_o}} \gamma_{j_k} \\ s.t. \quad & \frac{\sum_{r=1}^{s} p_r \hat{y}_{ro}}{\sum_{r=1}^{s} p_r y_{ro}} - \gamma_{j_k} = \frac{1}{\theta_{j_k}}, \quad j_k \in J_{k_o} \\ & \sum_{j=1}^{n} \lambda_j x_{ij} \leq x_{io} \quad , i = 1,...,m \\ & \sum_{j=1}^{n} \lambda_j y_{rj} \geq \hat{y}_{ro} \quad , r = 1,...,s \\ & \lambda_j, \hat{y}_{ro} \geq 0 \end{aligned} \tag{14}$$

$\hat{x}_{io}$ and y_{ro} are referred to DMU under evaluation in each group. Model (14) may be converted to model (15) as follows:

$$\begin{aligned} Min \quad & \sum_{j_k \in J_{k_o}} \gamma_{j_k} \\ s.t. \quad & \sum_{r=1}^{s} p_r \hat{y}_{ro} - (\gamma_{j_k} + \frac{1}{\theta_{j_k}}) \sum_{r=1}^{s} p_r y_{ro} = 0, \; j_k \in J_{k_o} \\ & \sum_{j=1}^{n} \lambda_j x_{ij} \leq x_{io} \quad , i = 1,...,m \\ & \sum_{j=1}^{n} \lambda_j y_{rj} \geq \hat{y}_{ro} \quad , r = 1,...,s \\ & \lambda_j, \hat{y}_{ro} \geq 0 \end{aligned} \tag{15}$$

After obtaining $\hat{y}_{ro}$, Equation (7) is used for calculating new revenue efficiency score for each DMU.

3. CASE STUDY

The case study of Iranian manufacturing industries is used to present some capabilities of the proposed models. Because of governmental structure in Iran and paying a large amount of energy subsidy to manufacturing units, it is necessary to evaluate energy resources in Iran. The data are taken from Iranian industries and their branches according to the

International Standard Industrial Classification (ISIC) of all economic activities provided by the United Nations Statistics Division (Revision 3). According to this standard, economic activities are classified into 17 main classes. Fourth class is manufacturing industries. Also, it includes 23 subclasses which are identified by two-digit numbers. Table 1 shows the details of these subclasses and their branches.

TABLE 1. Classification of manufacturing according to ISIC

Two-digit code	Class name	Three-digit code	Subclass name
15	Manufacture of food products and beverages	151	Processed meat, fish, fruit, vegetables, fats
		152	Dairy products
		153	Grain mill products; starches; animal feeds
		154	Other food products
		155	Beverages
16	Manufacture of tobacco products	160	Tobacco products
17	Manufacture of textiles	171	Spinning, weaving and finishing of textiles
		172	Other textiles
		173	Knitted and crocheted fabrics and articles
18	Manufacture of wearing apparel; dressing and dyeing of fur	181	Wearing apparel, except fur apparel
19	Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear	191	Tanning, dressing and processing of leather
		192	Footwear
20	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	201	Sawmilling and planning of wood
		202	Products of wood, cork, straw, etc.
21	Manufacture of paper and paper products	210	Paper and paper products
22	Publishing, printing and reproduction of recorded media	221	Publishing
		222	Printing and related service activities
		223	Reproduction of recorded media
23	Manufacture of coke, refined petroleum products and nuclear fuel	231	Coke oven products
		232	Refined petroleum products
24	Manufacture of chemicals and chemical products	241	Basic chemicals
		242	Other chemicals
		243	Man-made fibers
25	Manufacture of rubber and plastics products	251	Rubber products
		252	Plastic products
26	Manufacture of other non-metallic mineral products	261	Glass and glass products
		269	Non-metallic mineral products, n.e.c.
27	Manufacture of basic metals	271	Basic iron and steel
		272	Basic precious and non-ferrous metals
		273	Casting of metals
28	Manufacture of fabricated metal products, except machinery and equipment	281	Structural metal products, tanks, steam generators
		289	Other metal products; metal working services
29	Manufacture of machinery and equipment n.e.c.	291	General purpose machinery
		292	Special purpose machinery
		293	Domestic appliances, n.e.c.
30	Manufacture of office, accounting and computing machinery	300	Office, accounting and computing machinery
31	Manufacture of electrical machinery and apparatus n.e.c.	311	Electric motors, generators and transformers
		312	Electricity distribution & control apparatus
		313	Insulated wire and cable
		314	Accumulators, primary cells and batteries
		315	Lighting equipment and electric lamps
		319	Other electrical equipment, n.e.c.
32	Manufacture of radio, television and communication equipment and apparatus	321	Electronic valves, tubes, etc.
		322	TV/radio transmitters; line comm. apparatus
		323	TV and radio receivers and associated goods
33	Manufacture of medical, precision and optical instruments, watches and clocks	331	Medical, measuring, testing appliances, etc.
		332	Optical instruments & photographic equipment
		333	Watches and clocks
34	Manufacture of motor vehicles, trailers and semi-trailers	341	Motor vehicles
		342	Automobile bodies, trailers & semi-trailers
		343	Parts/accessories for automobiles
35	Manufacture of other transport equipment	351	Building and repairing of ships and boats
		352	Railway/tramway locomotives & rolling stock
		353	Aircraft and spacecraft
		359	Transport equipment, n.e.c.
36	Manufacture of furniture; manufacturing n.e.c.	361	Furniture
		369	Manufacturing, n.e.c.
37	Recycling	371	Recycling of metal waste and scrap
		372	Recycling of non-metal waste and scrap

For example, code 17 belongs to the manufacture of textiles and in itself it is classified into three branches that are identified by three-digit numbers.

Iran, similar to other developing countries, has several industries that need to be evaluated. Government of each country wishes to know which industries are efficient in energy resources and which are not, and therefore, must be improved. For this purpose, the data are taken from 23 manufacturing industries and the related branches in Iran. In such a circumstance, the multi-group cost efficiency model may be applied. The selected inputs are the amount of fossil fuel, water and electricity consumption as main energy resources in industries. Besides these energy resources, we consider the number of employees as an important input for units. Also, prices are considered for all inputs and the income is regarded as the output in model (11). Furthermore, the price of human resources, fuel, electricity and water are 3.4 (million monetary units), 73529.4 (per a barrel of oil), 375.1 (kWh) and 1385 (cubic meter), respectively, which are the same for all industries (because the government determines a constant price for all industries). Table 2 presents the characteristics of the inputs and the outputs for Iranian manufacturing systems based on ISIC code.

Table 3 presents the results of efficiency scores for the conventional DEA model versus the proposed multi-group DEA model (model (2)).

TABLE 2. Characteristics of the used data for Iranian manufacturing systems

Code	No. employees	Amount of fossil fuel consumption	Amount of water consumption	Amount of electricity consumption	Income
Max	157545	4994132	1326358	3249369	595457199
Min	12	6	1	18	1782
Mean	21164	264790.85	36337.76	230489.17	33098513
SD	28160	853706.98	173112.87	611742.71	88253028.39

TABLE 3. Efficiency scores of conventional DEA versus proposed DEA model

Unit	Conventional DEA efficiency scores	Proposed model efficiency scores (Model 11 and Equation (6))	Unit	Conventional DEA efficiency scores	Proposed model efficiency scores (Model 11 and Equation (6))
151	0.6529	0.1331	281	0.5718	0.4813
152	0.5995	0.1852	289	0.5701	0.5701
153	0.7159	0.3926	291	0.7585	0.4764
154	0.5165	0.037	292	0.4983	0.4368
155	0.5776	0.1403	293	0.668	0.668
160	1	0.4044	300	1	1
171	0.4618	0.082	311	0.7431	0.1945
172	0.527	0.1723	312	0.6789	0.3461
173	0.461	0.1345	313	0.7037	0.2886
181	0.5465	0.1662	314	0.7024	0.2581
191	0.6398	0.3447	315	0.5364	0.1011
192	0.437	0.1569	319	1	1
201	0.7442	0.7442	321	0.6731	0.2781
202	0.5569	0.2533	322	0.6198	0.2522
210	0.492	0.3162	323	0.8434	0.5231
221	0.5375	0.0783	331	0.6557	0.2209
222	0.4988	0.1778	332	1	0.3202
223	0.8177	0.8176	333	0.5209	0.2905
231	0.5808	0.1753	341	1	0.4726
232	1	0.5565	342	0.7522	0.7522
241	1	0.4307	343	0.6779	0.3185
242	0.7716	0.1876	351	0.8464	0.2761
243	0.6055	0.6055	352	0.4766	0.0878
251	0.5225	0.45	353	1	0.981
252	0.5364	0.5364	359	0.6889	0.3525
261	0.5991	0.5226	361	0.5183	0.1138
269	0.7906	0.0635	369	0.4802	0.0656
271	0.863	0.0463	371	1	1
272	0.8607	0.0747	372	0.31	0.032
273	0.5849	0.5849			

By comparing the results of the conventional DEA model and the proposed model, Figure 1 shows that the conventional DEA model provides more optimistic efficiency scores than the proposed model. Because these scores have large amounts for the most units and are not capable of good distinguishing and the efficiency scores are close together.

Table 4 summarizes the results of the proposed model. The second to the fifth columns present the calculated values of inputs. Some of the inputs must be increased, but most of them must be decreased in comparison with their original values. The summary of these results are presented in Table 4. The columns present the percent of increasing or decreasing the values of inputs. In human resources, most of the values are positive which indicates that most of the manufacturing units are inefficient in this input and must be decreased, despite the low level of price. On the other hand, due to low levels of the prices in other inputs (energy resources) in Iran, the energy consumption of manufacturing units is in excess of their optimum need. Hence, most of them must decrease the usage of these inputs. Note that the type of manufacturing systems affects the usage of inputs.

Besides, the government can remove the subsidies for manufacturing units in order to use the inputs efficiently. For example, the original efficiency of unit-332 is 1 which seems efficient.

By applying model (15), the efficiency score decreases to 0.32. This unit must decrease the fossil fuel (69%), electricity (55%) and water (37%) consumption, and instead it may increase the human resources (because of the low level of price).

On the other hand, unit-319 is efficient using both models and according to Table 4, there is no necessity of changing inputs.

4. SUMMARY AND CONCLUSION

This paper proposes an approach for evaluating energy resources of manufacturing systems. Manufacturing industries according to ISIC codes are classified into several classes and subclasses.

The conventional DEA models are unable to be applied in this state. For this purpose, Cook and Zhu (2007) proposed within-group DEA. Their model does not consider inputs/outputs prices for resources. Furthermore, the structure of the proposed nonlinear model causes a problem for using and solving such models. Therefore, the multi-group cost/revenue efficiency model has been presented. The proposed model is a linear model and is solved easily. Also, increase or decrease in the inputs level and optimal values were calculated. According to results, the average efficiency score obtained from the conventional DEA is 0.678, whereas the average efficiency score for the proposed model is 0.358. It shows that the conventional model provides very optimistic scores for units. Furthermore, the conventional model detected nine units as efficient. Therefore, these efficient units cannot be ranked, whereas the efficient units were reduced to three in the proposed model. Moreover, expanding DMUs levels, considering different objectives for each level and applying other models are some suggestions for the further researches.

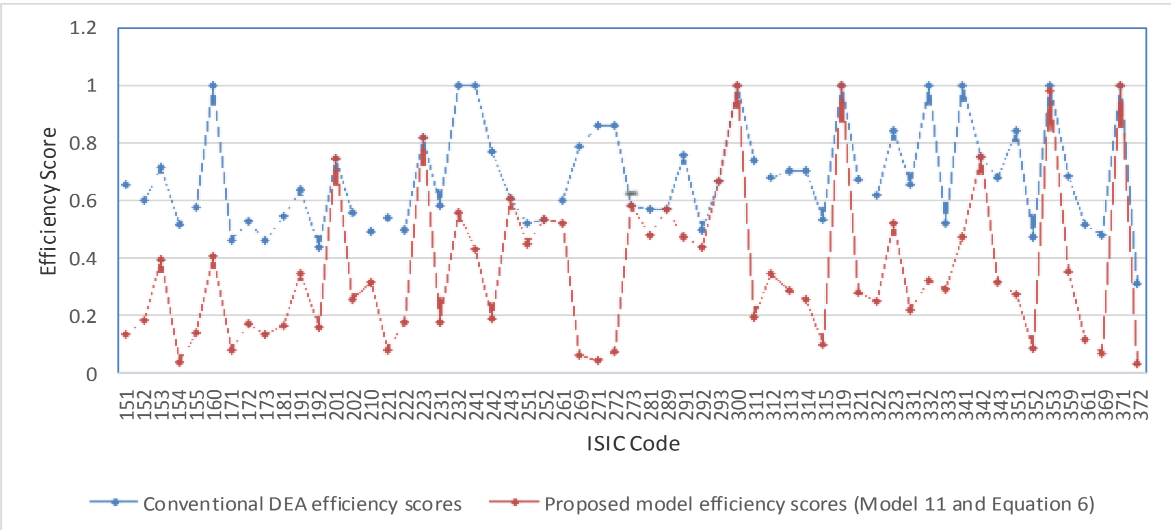

Figure 1. Comparing efficiency scores of the conventional DEA model and the proposed multi-group model

TABLE 4. Increase/decrease in inputs level (%)

Code	No. employees	Amount of fossil fuel consumption	Amount of water consumption	Amount of electricity consumption	Code	No. employees	Amount of fossil fuel consumption	Amount of water consumption	Amount of electricity consumption
151	-3.82	87.18	89.37	40.78	281	86.43	51.66	92.54	80.65
152	-79.42	82.05	89.81	56.16	289	82.40	42.72	85.70	79.16
153	-48.82	61.04	88.65	53.24	291	66.96	52.55	83.29	55.01
154	34.98	96.45	97.29	68.18	292	87.37	56.01	93.85	87.57
155	-165.43	86.38	95.93	68.43	293	80.58	32.90	86.70	67.55
160	58.04	60.74	61.75	-192.65	300	20.23	3.82	40.78	36.98
171	58.02	92.02	93.21	89.04	311	-20.32	81.19	86.10	47.83
172	45.59	83.27	88.93	67.51	312	-175.87	66.41	78.42	39.45
173	66.32	86.99	91.20	75.20	313	-26.70	71.87	77.98	51.08
181	74.03	84.74	-56.67	26.36	314	-38.99	74.79	66.76	71.57
191	29.29	84.00	93.60	47.09	315	-64.09	90.31	86.10	58.90
192	68.54	84.62	85.65	81.45	319	0.00	0.00	0.00	0.00
201	97.68	25.56	30.65	85.29	321	45.32	72.74	89.97	19.18
202	79.85	74.63	77.62	90.44	322	66.25	75.00	83.69	51.89
210	84.20	68.36	68.85	79.08	323	27.88	48.82	61.32	8.59
221	65.97	92.46	84.59	77.86	331	47.48	78.57	88.73	47.58
222	63.96	82.71	89.96	69.26	332	-75.49	68.98	55.55	37.35
223	63.96	28.26	81.83	38.87	333	66.10	71.57	84.04	60.06
231	30.97	83.10	80.08	41.75	341	67.38	54.19	-16.67	-83.74
232	-112.69	44.39	66.56	47.14	342	74.58	24.66	38.47	52.71
241	61.23	57.51	-2.09	78.02	343	16.36	69.01	71.97	37.78
242	2.39	81.88	87.47	34.45	351	-5.29	73.14	91.84	25.47
243	85.36	39.29	88.17	83.50	352	91.38	91.30	97.96	80.18
251	82.33	54.77	88.55	88.43	353	55.08	0.23	-165.56	42.06
252	81.98	45.24	92.35	89.97	359	14.62	65.62	80.59	25.79
261	97.81	47.56	85.35	98.13	361	66.97	89.04	86.15	63.80
269	86.93	93.66	94.08	96.62	369	63.24	93.68	95.08	75.55
271	-123.80	95.54	92.05	88.51	371	91.67	-1.45	-10.62	91.34
272	-110.84	92.64	90.46	94.64	372	83.01	96.92	97.45	88.32
273	88.86	39.36	97.37	97.03					

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Energy Resources Consumption Performance in Iranian Manufacturing Industries by Using Cost/Revenue Efficiency Model

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چکیده

صنایع یک از منابع اصلی ایجاد کننده آلودگی در جهان می باشد. در کنار این امر، سطح مصرف منابع انرژی شامل آب، برق و سوختهای فسیلی در میان صنایع مختلف، متفاوت می باشد. از طرف دیگر، دولت ایران حجم وسعی یارانه به واحدهای صنعتی می پردازد. به خاطر این، دولت تمایل دارد که بداند چه صنایع از لحاظ مصرف انرژی کارا بوده و آلودگی کمتری تولید می کنند و در نتیجه باید حمایت بیشتری بشوند. در کنار این، صنایع ساخت و تولید به گروههای مختلفی تقسیم بندی می شوند. در این مقاله، مل مرسوم تحلیل پوششی داده‌ها به حالت چند دسته‌ای به منظور ارزیابی صنایع ساخت و تولید توسعه داده می‌شود. مشخصه اصلی مدل پیشنهادی در نظر گرفتن قیمت ورودیها و خروجیها در فرایند ارزیابی می باشد. به عبارت دیگر، یک مدل خطی کارایی هزینه/درآمد گروهی ارائه خواهد شد. داده‌های ۵۹ صنعت موجود در ایران که در ۲۳ کلاس طبقه بندی شده اند مورد استفاده قرار خواهد گرفت. ورودیها شامل منابع انرژی از قبیل میزان سوخت فسیلی، میزان برق مصرفی و میزان آب مصرفی و همچنین منبع غیر انرژی مانند تعداد نیروی کار می‌باشد. نتایج نشان می دهد که میزان کارایی و عملکرد انرژی صنایع مختلف به میزان قابل توجهی در صورت ارزیابی هر صنعت با گروه مربوط به خودش متفاوت خواهد بود.

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