The Effects of Non-Controllable Factors in Efficiency Evaluation of Turkish Coal Enterprises

Yasar Kasap[1], Adnan Konuk[1], Rafail N. Gasimov[2], and Ahmet Mahmut Kiliç[3]*

[1]Eskisehir Osmangazi University, Faculty of Engineering and Architecture, Department of Mining Engineering, 26480, Eskisehir-Turkey

[2]Eskisehir Osmangazi University, Faculty of Engineering and Architecture, Department of Industrial Engineering, 26480, Eskisehir-Turkey

[3]Çukurova University, Faculty of Engineering and Architecture, Department of Mining Engineering, 01330, Adana-Turkey

ABSTRACT

In this study, which aims to examine the effects of non-controllable factors as well as input parameters on the efficiency performances of Turkish Coal Mine Enterprises, eight enterprises within Turkish Coal Enterprises (TCE) were examined. In order to keep the study as up-to-date as possible, data from the latest year (2005) was examined. For each enterprise, the outputs consisted of the amount of the production sold and the total income gained in the corresponding year; the controllable inputs consisted of investment expenditure, overburden stripping and number of staff; and non-controllable inputs consisted of total reserve and low heat values. In order to measure the effects of non-controllable inputs on enterprise efficiency, three-stage modified data envelopment analysis (DEA) model was employed. In the first stage, information concerning the efficiency of the enterprises was gained by using only the controllable inputs and outputs. In the second stage, the effects of non-controllable inputs on controllable inputs in inefficient enterprises were examined. Lastly in the third stage, the new efficiency values were calculated by means of DEA where controllable inputs and outputs modified according to non-controllable inputs were used. Considering the non-controllable inputs as a result of the analyses conducted with three-stage DEA model, it was determined that the average efficiency value of Turkish Coal Enterprises increased from 87.5% to 92.3%.

Keywords: Data envelopment analysis, Non-controllable inputs, Coal sector.

1. INTRODUCTION

The demand for energy is increasing tremendously in parallel with the population growth, industrialization and technological advances around the world. Energy, the very source of economic progression and social development, is becoming one of the

*Corresponding Author. Fax: +90 322 3386126; E-mail: kilicm@cu.edu.tr

key factors in the economic growth of a country and prosperity of its people. Coal (lignite and hard coal) – with a 70%proportion among reserves like petroleum, natural gas and alike that constitute the energy resources apart from nuclear energy – is considered as the energy resource of future.

Coal is one of the major fuel sources used for electric power generation. More than half of the world's total coal production currently provides around 37% of the world's electricity (Kiliç and Kiliç, 2006). This ratio is 53% in the USA and Germany, 69% in Greece, 75% in China, 77% in Denmark, 83% in Australia, and 95% in Poland. 32% of electricity energy in Turkey is provided from coal (tki.gov.tr, 2004). In addition to electric production, coal can be utilized in various important fields such as steel and cement manufacture, and industrial process heating. In the developing world, the use of coal in the household, for heating and cooking, is also important (WCI = World Coal Institute, 2005). According to WCI 2004 data, thermal coal has grown by about 7% per annum over the last 20 years.

Coal is generally the only alternative when low-cost, cleaner energy sources are inadequate to meet increasing energy demand. Developing countries utilize about 55% of the world's total coal today. This percentage is expected to increase to 65% over the next 15 years. In 2050, coal will account for more than 20% of the world's primary energy (Balat and Ayar, 2004).

In Turkey, which can be considered rich in terms of lignite reserves, it is vital that production level of coal, capable of meeting the energy demand to a large extent, be increased so that it is managed economically as the most common natural resource. On the other hand, there are some major difficulties in finding new reserves and financing investments. Efficiency-increasing activities are needed urgently in order to manage the present reserves at an optimum level, to decrease the dependency on foreign countries and to make up an efficient alternative for other energy resources. Therefore, measuring the technical efficiency, which is the achievement criterion in measuring to what extent an enterprise produces the most number of outputs by using the combination of inputs it possesses in the most proper way, was evaluated to be appropriate.

The following led us to Data Envelopment Analysis (DEA): actual production function of the enterprises to be subject to efficiency evaluation is never known and it is thought that accurate results can never be obtained when the functional form to be determined is wrong; it makes it possible to evaluate many variables and constraints together and allows for carrying out guide analyses and interpretations by means of the wide theory and methodology mathematical programming offers us.

DEA is a linear programming-based technique aiming to measure the relative performance of decision-making units when inputs and outputs with more than one and different units make comparing process difficult.

Standard DEA, which is commonly used in efficiency analysis and has innumerable applications, assumes that the units determined are homogeneous units which realize the same tasks with similar objectives, which produce similar outputs by using similar inputs and which operate in similar environments (Golany and Roll, 1989). Those environments considered to be homogeneous could usually be spoiled due to the non-discretionary environments and the inputs used in analyses could require different

environments. These inputs which are not controlled by DMUs and which influence efficiency score are generally called non-discretionary factors (Syrjanen, 2004).

Taking the environmental factors into consideration and suggesting that the amount of the outputs produced by an enterprise is influenced by some factors other than the inputs, Charnes (1980) divided the variables employed in efficiency measurement into two groups: discretionary and non-discretionary variables. Non-discretionary variables consist of suitable or unsuitable factors which influence the performance of each producer and the results from the calculated DMUs and which reflect both organizational and management constraints and different features (Muniz, 2002).

The presence of non-discretionary inputs in efficiency index calculation leads us to make a distinction between two main effects as producer activity and the practical conditions of production process. The distinction between these effects is necessary when a careful measurement of producer activities and an accurate interpretation are desired. Besides, determining and examining efficiency in detail will be needed in order to improve the results from the calculated units (Muniz, 2002).

In the standard DEA models developed by Charnes et al. (1978) and Banker et al. (1984), non-discretionary factors are treated as ordinary discretionary factors helping examine the efficiency and they are completely excluded from the process. Therefore, many models were developed aiming to take non-discretionary inputs into consideration. In this study, the model developed by Fried and Lovell (1996) and then modified by Muniz (2002), one of the models mentioned in the second chapter, was used.

The reasons why this model was chosen are that it was developed with the aim to eliminate the limitations of the other models taking non-discretionary factors into consideration in non-parametric efficiency analysis and that it also aims to increase the net efficiency of DMUs under the influence non-discretionary inputs; in other words, it is capable of excluding the constraints caused by non-discretionary factors and technical inefficiency. Due to the fact that mining sector depends heavily on environmental conditions and it contains some uncertainties, conducting a study like this one was thought to be appropriate to examine whether non-discretionary variables have an influence over the efficiency measurement in this sector or not.

Despite the considerable number of studies in literature conducted into DEA, there are very few number of studies in which the productivity and efficiency in mining sector are measured through DEA. It was observed that none of the studies examined took non-discretionary factors into consideration to a sufficient degree. Two studies were conducted into DEA in mining sector. Kulshreshtha and Parikh (2002), between 1985 and 1997, tried to determine the efficiency and productivity through DEA by using the yearly data of the mining machinery in 30 sites belonging to the underground and opencast coal mining of India. Despite their effort to take non-discretionary factors into consideration in their study, they could not collect detailed data concerning non-discretionary inputs caused by the use of one-stage model developed by Banker and Morey (1986) (Kulshreshtha and Parikh, 2002). Thompson and Thrall stated in their theory that profitableness ratios and technical efficiency examined by using Data Envelopment Analysis ought to be regarded separately. This issue was proven by using the data from Illinois coal mine. As a result, it was proven that DEA technical efficiency did not bring about DEA maximum profit ratio; on the

contrary, DEA maximum profit ratio did bring about DEA technical efficiency (Thompson et al., 1995).

Byrnes et al. (1998) examined US coal mining by means of two analytical techniques: mathematical programming and regression analysis. Showing that non-parametric mathematical programming let distinctions such as technical efficiency and measurement efficiency, it was proven to be superior to the other method as a guideline for managers.

Byrnes and Fare examined the relative efficiency of US opencast coal mines in 1987. The research was conducted on a total of 186 samples through a non-parametric and non-stochastic method and the efficiency of each firm was calculated relatively with fragmentary linear technology and the causes of the inefficiency were defined.

Our aim is to determine to what extent mining enterprises use their present resources efficiently and which enterprises display a more successful performance regarding the most efficient use in comparison with others and to advise unsuccessful enterprises by considering the non-discretionary factors in order to reduce the growing coal deficiency. To this end, this study tried to carry out performance analyses for the eight sectors/regions (with several enterprises) operating under Turkish Coal Enterprises, examined the effect of non-controllable inputs and stated that non-controllable variables like reserve and low heat value relatively influenced operating efficiency.

After this introductory part, the 2nd part gives brief information about standard DEA and provides a detailed explanation of Fried-Lovell and Muniz model, which forms the foundation of this study. The practical phase of the model with actual data from TCE is presented in the 3rd part and the results gained are discussed in the 4th part.

2. PROBLEM FORMULATION AND MATHEMATICAL MODEL

The methods to measure efficiency, which is defined as the achievement to produce as much output as possible with the inputs consumed or to obtain a certain output composition, are classified into two main headings as ratio analysis and frontier efficiency approach. Ratio analysis includes one-dimension analyses in terms of scope and objective. The need to gain a single criterion by weighing different ratios calculated in efficiency measurement is stated to be the most important drawback of ratio analysis method. In frontier efficiency approach, on the other hand, the most efficient frontier is determined first and then relative efficiencies of DMUs in the problem are measured. Production frontier could be measured through a special functional form or limited parameters and by using parametric or non-parametric approaches. Parametric approaches assume that the production function about the enterprises where efficiency measurement is realized has an analytical structure. Since production function is not known in practice, Farrell (1957) suggested estimating the function by using the data in sample. The first suggestion was evaluated by Charnes, Cooper and Rhodes and this led to emergence of non-parametric Data Envelopment Analysis (DEA) (Atan, 2005; Kaya and Dogan, 2005; Tarim, 2001; Yu, 1998). Data Envelopment Analysis is a linear programming-based technique aiming to measure the relative efficiency of decision-making units when inputs and outputs measured with several and different scales or those with different measuring units make comparing process difficult (Banker, 1992).

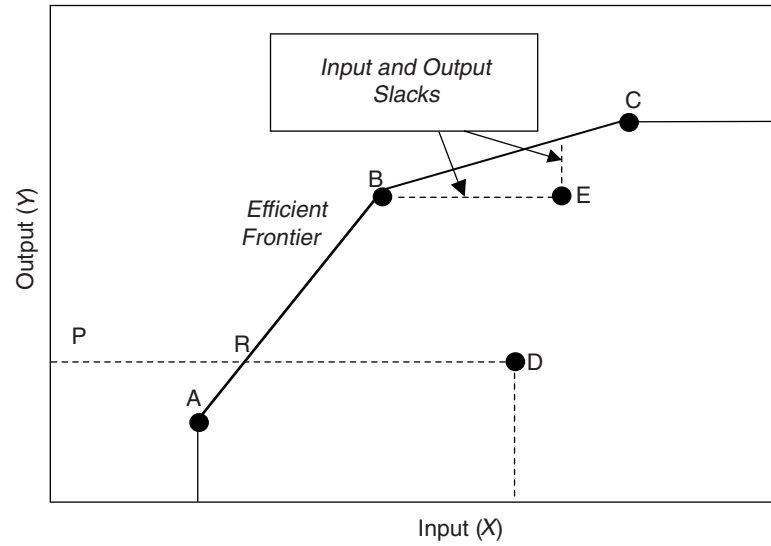

Figure 1. Input-oriented standard VZA (Technical Efficiency).

By determining a frontier (efficient frontier = enveloped surface) composed of relatively efficient ones (A, C, F) among DMUs performing the same production activity through mathematical programming principles, DEA, used for comparative efficiency analysis, is a technique that can determine the performance of the relatively inefficient units (B, D, E) within the extent they are far from this frontier. A, B, C, D, E, and F points are presented in Figure 1. illustrating the efficient frontier express DMUs.

Non-controllable factors in standard DEA models are treated as if they were normal optional factors helping to examine efficiency and their effect is not taken into consideration. Many different approaches were developed in order to eliminate this drawback (Syrjanen, 2004).

Established by Banker and Morey (1986) and later developed by Golany and Roll (1993), the first DEA model using non-controllable inputs consisted of a single stage. Environmental differences are not taken into consideration in these efficiency measurement models, which evaluate controllable and non-controllable factors simultaneously and require just one DEA. In other words, controllable or non-controllable factors are all treated as controllable factors or they are completely excluded from analysis. Therefore, they do not allow examining the effects other than managerial control.

Ruggiero (1996) developed an alternative model aiming to eliminate the drawbacks of the model by Banker and Morey. However, it came out that the performance of this model also, on the condition that other values were equal as well, decreased as the number of non-discretionary inputs increased and it tended to define DMUs as efficient (Muniz et al., 2006).

Ray (1991) and Ruggerio (1998) developed multi-stage models proposing the use of regression to establish a detailed index about non-controllable factors. Regression analysis is realized in the second stage of these models. Because regression analysis initially requires a functional form, it should be noted that its measurements will be inaccurate if the functional form assigned is incorrect as well (Muniz et al., 2006).

Fried and Lovell (1996), therefore, developed a model consisting of three different data envelopment analyses in order to eliminate the drawbacks of the other models taking non-controllable inputs into consideration and to increase the net efficiency of DMUs. While only controllable variables are considered in the first stage of this model, later modified by Muniz (2002), the effect of non-controllable variables is examined in the other two stages (Torrubia et al., 2004; Muniz, 2002).

The rationale for DEA models is the use of radial component under input minimization and output minimization. Adhering only to this radial component causes a loss of information that could be avoided through the use of total slack. The only feature that distinguishes the model by Fried-Lovell and Muniz from the previous ones is the use of total slacks (radial and non-radial (Muniz, 2002).

In this study, since the objective was to examine if the non-discretionary inputs in the sector had an influence over mining enterprise efficiency or not, an input-centered application was realized. If non-discretionary outputs were taken into consideration, an output-centered application would have been needed.

The symbols used in the formulation of the three-stage DEA model which forms the foundation of this study are defined below.

Sets and parameters

n number of decision making units where comparison is realized,
s number of outputs gained from production,
m number of inputs used in production,
p number of non-controllable factors affecting production,
k $= (1,2,\ldots,n)$ set of decision making unit considered,
j $= (1,2,\ldots,n)$ set of all decision making units,
r $= (1,2,\ldots,s)$ set of all outputs,
i $= (1,2,\ldots,m)$ set of all inputs,
l $= (1,2,\ldots,p)$ set of all non-controllable factors,
θ_k scalar variable (efficiency value) trying to increase all inputs of k DMU considered to gain the best frontier,
λ_j the weighted value j decision making unit gets for controllable factors,
Y_{rj} the rth output amount produced by j decision making unit,
Y_{rk}^* the arranged r^{th} output amount of k decision making unit,
s_{rk}^- slack value (the output not produced in sufficient amounts) of the rth output of k decision making unit (which cannot be measured with DEA in "radial" terms but can be increased),
X_{ij} the ith input amount used by j decision making unit,
X_{ik}^* the arranged i^{th} output amount of k decision making unit
s_{ik}^+ slack value (controllable input used in excess) of the ith output of k decision making unit (which cannot be measured with DEA in "radial" terms but can be increased),

β_k scaler variable trying to decrease all slack variables of k DMU considered to gain the best frontier,
μ_j the weighted value j decision making unit gets for non-controllable factors,
Z_{lj} the lth non-controllable input amount used by j decision making unit,
s_{lk}^{*} slack value of the lth non-controllable output of k decision making unit (which cannot be measured with DEA in "radial" terms but can be increased),
S_{ij}^{+} the ith input amount of j decision making unit arranged by considering obtained slack variables and radial inefficiency ($S_{ij}^{+} = (1-\lambda)_j \cdot X_{ij} + s_{ij}^{+}$),
S_{rj}^{-} the rth output amount of j decision making unit arranged by considering obtained slack variables ($S_{rj}^{-} = s_{rj}^{-}$),
s_{ik}^{++} slack value of the slack variable of k decision making unit's i^{th} input (which cannot be measured with DEA in "radial" terms but can be increased),

2.1. First Stage

The objective at this phase is to determine the slack variables at the first stage for each DMU (s_{ij}^{+} , inputs used extensively or s_{rj}^{-} outputs not produced in sufficient amounts) by means of the standard DEA where only discretionary variables are taken into consideration.

The model established under input minimization is as follows:

Objective function

$$\min \theta_k \tag{1}$$

Constraints

$$\sum_{j=1}^{n} \lambda_j \cdot Y_{rj} - s_{rj}^{-} = Y_{rk} \qquad (r = 1, 2, ..., s), \tag{2}$$

$$\sum_{j=1}^{n} \lambda_j \cdot X_{ij} + s_{ij}^{+} = \theta_k \cdot X_{ik} \qquad (i = 1, 2, ..., m) \tag{3}$$

$$\sum_{j=1}^{n} \lambda_j = 1 \tag{4}$$

$$\lambda_j, s_{ij}^{+}, s_{rj}^{-} \geq 0 \qquad (j = 1, 2, ..., n). \tag{5}$$

At this point, the input amounts used by inefficient mining enterprises are compared according to the minimum input amounts (constraint 3) determined through the efficient limit to produce constant output (constraint 2) and data is collected about the efficiency scores of the enterprises and slack variables.

Figure 1 exhibits 4 DMUs A, B, C and D, each with one input and one output. The technical efficient frontiers consist of A, B and C. The input oriented technical efficiency of D is evaluated by,

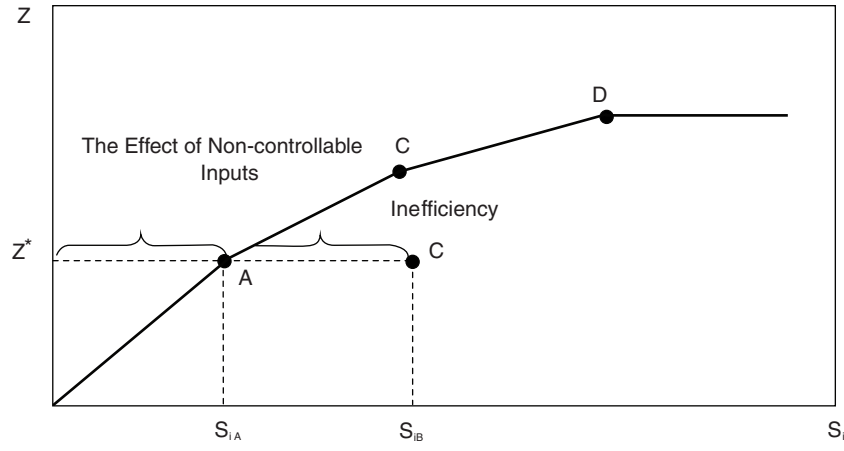

Figure 2. Partition of the initial slack carried out in the second stage.

$$TechnicalEfficiency = \frac{PR}{PD}$$ (Cooper et al., 2000).

2.2. Second Stage

The slack variables determined at the first stage emerge due to two different effects. First one is the effects of non-discretionary inputs ($\beta_k[(1-\theta_k) \cdot X_i + s_i^+]_j$) and the other is the technical inefficiency emerging during the production ($(1-\beta_k)[(1-\theta_k) \cdot X_i + s_i^+]_j$). The aim of the second stage is to determine the amounts and differences between the two effects.

Total slack value gained from the first stage ($S_{ij}^+ = (1-\theta_k)_j \cdot X_{ij} + s_{ij}^+$) is used to determine the efficient frontier points. The object of this stage is to minimize the slack value in a variable attributable to non-controllable input value, in other words, to condition non-controllable inputs by means of their observed values.

The second stage is expressed as follows (as stated above for model X_i variable and will be similar for Y_r variable excluded from total slack value) (Muniz et al., 2006; Muniz, 2002; Bosch et al., 2001).

Objective function

In this stage, formed by DEA using non-discretionary factors and total slacks, the objective function used to minimize the slack value in a variable attributable to non-controllable input value is as follows;

$$\min \beta_k \tag{6}$$

Constraints

$$\sum_{j=1}^{n} \mu_j \cdot Z_{lj} - s_{lk}^* = Z_{lk} \qquad (l = 1, 2, ..., p), \tag{7}$$

$$\sum_{j=1}^{n} \mu_j \cdot S_{ij}^{+} + s_{ik}^{++} = \beta_k \cdot S_{ik}^{+} \qquad \text{(i = 1, 2, .., m),} \qquad (8)$$

$$\sum_{j=1}^{n} \mu_j = 1 \qquad (9)$$

$$\mu_j, s_{rk}^{*}, s_{ik}^{++} \geq 0 \qquad \text{(j = 1, 2, ..., n).} \qquad (10)$$

The frontier created for each variable at this the second stage is presented in Figure 2. A controllable input i and only one non-controllable input amount Z was dealt with in order to be explanatory. The aim here is to calculate the frontier formed by minimum slack S_j gained through each DMU for the given value of the non-controllable input Z.

The envelopment is determined by efficient DMUs. An efficient DMU can be associated with positive slacks, as occurs with A DMU in Figure 2 (S_{jA}), where this is the minimum slack that A could achieve for the value Z^* of its non-controllable input (Z^* is the amount of non-controllable input yielding the minimum slack value).

To analyze the situation in the case of an inefficient DMU, B, it is assumed to be efficient producer, such as A, for which value Z^* is the same. Let the slack be S_{jB}. It devides this value into the amount that the efficient producer, A, would produce, S_{jA}, which is considered the minimum achievable, and the difference ($S_{jB} - S_{jA}$) which is considered to be due to the inefficient of B DMU (Muniz, 2002; Torrubia et al., 2004).

The following step after the calculation in detail is to adjust the original data of each unit. The slack variable parts attributable to non-controllable inputs are the value on the frontier (consisting of the minimum slack variables calculated by each unit for the given value of their non-controllable inputs) in the second stage. According to the modification by Muniz (2002), on the other hand, if the original value of the outputs increases (decreases in the case of non-controllable inputs), non-controllable inputs will adequately compensate for the effects in relative terms. In other words, the minimum slacks obtained in the second stage will be excluded from (added to) the original values of controllable inputs (outputs) (Muniz et al., 2006; Torrubia, 2004; Bosch et al., 2001).

The new values can be expressed as the following:

$$X_{ij}^{*} = X_{ij} - \beta_k \cdot S_{ij}^{+} \qquad (\Lambda i = 1, ..., m)$$

$$Y_{rj}^{*} = Y_{rj} + S_{rj}^{-} \qquad (\Lambda r = 1, ..., s)$$

where $S_{rj}^{-} = s_{rj}^{-}$.

2.3. Third Stage

The efficiency of the producers is evaluated with the DEA carried out after the original values are modified in this manner (in other words, after the effect of the non-controllable inputs on the producers is compensated). The slack variables detected at

Table 1. Turkey's coal reserves (MENR, 2005)

Reserves	Proven	Probable	Possible	Total	
	Mt*	Mt	Mt	Mt	%
Hard coal (HC)	428*	456	245	1.129	10.33
Lignite (LG)					
Elbistan region	3.357	-	-	3.357	30.72
Other	3.982	626	110	4.718	43.17
Total	7.339	626	110	8.075**	73.89
Asphaltite	45	29	8	82	0.75
Bituminous shale	555	1.086	-	1.641	15.01
Total	8.367	2.197	363	10.927	100.0

*Available reserves are included.

**It reaches 8.375 *Mt (Million tons) by adding identified and potential sources of 300 Mt.

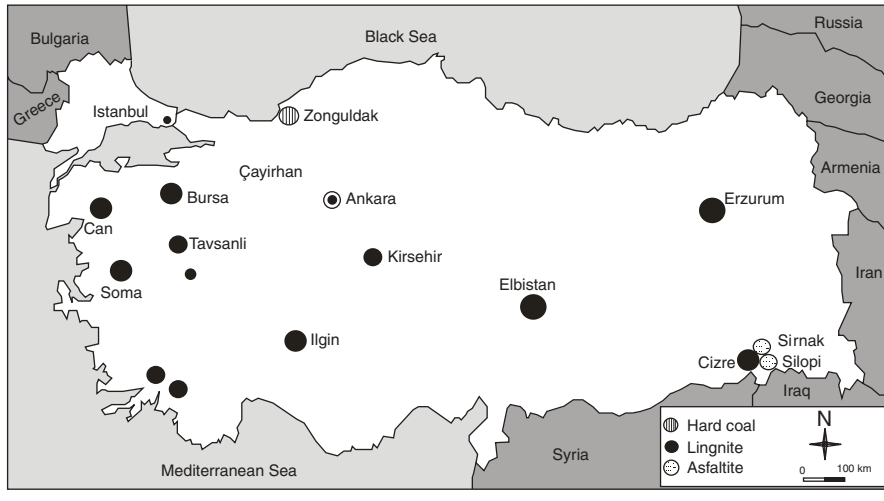

Figure 3. Coal deposits in Turkey.

this stage will be caused by the inefficient performance of the producer (Muniz et al., 2006; Bosch et al., 2001).

3. APPLICATION

Turkey produced 48.18 million short tons and consumed 63.54 million short tons in 2003. Coal consumption amounted to 30% of total energy consumption in Turkey (MENR = Ministry of Energy and Natural Resource, 2005).

In Turkey, terrestrial Tertiary reserves with coal bearing potential cover approximately 110.000 km^2. This area has been examined by the Turkish General Directorate of Mineral Research and Exploration, and an area of 41723 km^2 that appeared to be the most promising for coal mining has been geologically mapped (in scales of 1/25.000 and

Table 2. Distribution of Turkey's lignite reserves by region (MENR, 2005)

Regions	Total Reserve (Mt)	% of Total
The Marmara	825	9.85
Black Sea	215	2.57
Central Anatolia	1.325	15.82
Southeast Anatolia	53	0.63
Aegean	2.014	24.05
East Anatolia	3.580	42.75
Mediterranean	363	4.33
Total	8.375	100.0

Table 3. Distribution of Turkey's lignite reserves according to the LHVs (SPO = State Planning Organisation, 2004)

LHV		Reserve	
kcal/kg	kJ/kg	Mt	% of Total
<1.000	<4187	265	3.16
1.000–2.000	4187–8374	5492	65.58
2.000–3000	8374–12561	2038	24.34
3.000–4.000	12561–16748	429	5.12
>4.000	>16748	151	1.80
Total		8375	100

1/10.000) and checked by drill holes with a total length of more than 1.212.000 m. Drill-hole intervals lies between 50 and 2650 m. After detailed studies, the extent of the coal-bearing formations was determined to be about 1473,9 km^2. The thickness of coal seams lies between 0,05 and 87 m, with a maximum depth of coal seam from surface being 828 m (Tuncali and Ocakoglu, 1995; Gokmen et al., 1993).

Turkey's coal reserves in 2004 are shown in Table 1. As it can be seen in this table, Turkey has mainly both HC and LG reserves. The HC is abundant in and around Zonguldak which has more than 428 Mt of proven reserves. In addition, it is estimated that approximately 20 Mt reserves may be found in the Toros Mountains and in the Diyarbakir province (WECTNC = World Energy Council Turkish National Commitee, 2004). The map describing the coal reserves of Turkey is presented in Figure 3.

Rich LG deposits are spread all over the country. The most important reserves are in the Afsin-Elbistan, Mugla, Soma, Tuncbilek, Seyitomer, Beypazari, and Sivas regions. Total LG reserves are estimated to be about 8.375 Mt as of 2004. Table 2 and Figure 3 illustrate the distribution of the Turkish LG reserves by region (MENR, 2005).

There is a large variety of LG reserves in Turkey. They differ in their contents of moisture, flash, sulphur, calorific value, etc. The large quantity of LG with low quality is abundant. Only 14% of Turkey's coal reserves have moisture content below 20%. The average rate of moisture content is 40% in all LG reserves. Reserves bearing low ash contents are not abundant. About 69% of Turkey's LG reserves consist of the LGs with

Table 4. Chemical characteristics of Turkish lignites used in thermal power plants in Turkey

Chemical Characteristics	Lower and Upper Limits*	Weighted Averages**
LHV (kJ/kg)	1050–3300	1600
Moisture (%)	18–58	41
Ash (%)	15–50	28
Fixed carbon (%)	11–34	24
Volatile matter (%)	10–35	22
Total sulphur (%)	0.5–6	2

*Figures are rounded to one significant figure.

**Weighted average is based on the lignite consumption rate (tons/h) in the thermal power plants.

a LHV(Low Heat Value) of 8374 kJ/kg, as seen in Table 3. Better quality LG of over 12561 kJ/kg only accounts for approximately 7%. The sulphur rate ranges from 1% to 6% (Kural, 1999). The chemical characteristics of Turkish lignites are given in Table 4.

In Turkey, which can be considered rich in terms of lignite reserves, it is vital that the resources be used efficiently so that the present reserves can be managed at optimum level.

3.1. Data and Variables

Using DEA, the model made use of the 2005 data from eight enterprises of Turkish Coal Enterprises. The data was collected from Turkish Coal Enterprises (TCE). As TCE is an organization possessing about 80% of domestic reserves, access to proper data concerning the lignite production of the country is possible only through this institution. Aiming to increase the production, to perform studies to improve coal quality and to minimize coal production expenditure, TCE has a total of four institutional directorates in Turkey (Soma, Yatagan, Tavsanli and Seyitomer) that realize production and marketing activities and a total of four Enterprise Directorates working under them (Can, Milas, Ilgin and Orhaneli). Since many mining enterprises of Turkey operate under these 8 directorates, gaining proper data was possible only in this way. Therefore, it was regarded appropriate to perform an evaluation within the limits of these directorates.

For the sake of the reliability of the study in DEA, it is crucial that the number of decision making units be at least one more than the sum of the number the inputs chosen and that of outputs. In other words, assuming that the number of the inputs chosen in DEA is i and the number of the outputs is r, a minimum number of $i + r + 1$ decision making units is a requisite constraint for the sake of the reliability of the study. In this respect, it is thought that reliable results have been gained as the number of DMUs in the application (8 units) is one more than the sum of the numbers of inputs and outputs used.

Sets and parameters

n eight enterprises (Soma, Can, Yatagan, Milas, Tavsanli, Ilgin, Seyitomer, Orhaneli),

s number of outputs obtained from production (amount of production sold, total income),
m number of inputs used in production (investment expenditure, overburden stripping, number of staff),
p non-controllable factors having effect on production (total reserve, low heat value),
k = (1, 2, …., 8) set of decision making unit taken into consideration,
j = (1, 2, …., 8) set of all decision making units,
r = (1, 2) set of all outputs,
i = (1, 2, 3) set of all inputs,
l = (1, 2) set of all non-controllable factors.

Two outputs, three controllable inputs and two non-controllable inputs were taken into consideration in the analysis. Considerable attention was given to make sure that the inputs and outputs were the sets representing the production technology best. For each enterprise, outputs consist of the amount of the production sold (the amount of the coal sold in tons in the corresponding year) and the total income gained (the money gained from the coal sold in YTL). Although the production sale amount and the total income seem to be same variables, they refer to different variables because the unit prices in mining sector vary depending upon the quality parameters of coal (calorific value, sulfur ratio, humidity, ash content and so on) and where it is sold (teshin or thermoelectric power plant).

Of the discretionary inputs, investment cost refers to the expenditure occurring due to investment activities of the enterprise (YTL) in the corresponding year and is one of the inputs playing a key role in a mining enterprise beginning to operate. As opencast method is applied in the majority of the DMUs examined, overburden stripping was thought to be one of the inputs required to be taken into consideration. Overburden ratio expresses the percentage of the volume of stripped surface in open cast mining to tons of deposits (m^3/ton). The number of the staff was regarded as another input. The number of staff refers to the number of people working in the enterprise. Using this input was considered to be appropriate in terms of the accuracy of the analysis because more clear data about the number of staff was provided by TCE. Other discretionary inputs such as fuel and equipment, which are commonly used in productivity and efficiency analyses, could have been included in the analysis. In DEA, however, the number of DMUs is determined based on the number of inputs and outputs. The 8 units of DMUs used in the application brought a limit to the number of inputs and outputs.

Coal deposit and low heat value expresses non-controllable inputs in mining sector. Reserve represents the certain amount of unprocessed mine (10^3 ton) that is economical and display some kind of certainty in short term and low heat value represents the heat value (kcal/kg) emerging when a kilo of a material is burnt. Reserve and low heat value were regarded as non-discretionary inputs since the former is one of the parameters which determine the investment cost and the latter is one of the parameters determining the quality, and therefore the unit price. The data used is presented in Table 5.

Table 5. The data used

Enterprises (j) (k)	Non-Controllable Inputs		Controllable Inputs			Outputs	
	Total Reserve Z_1 (10^3 ton)	Low Heat Value Z_2 (Kcal/kg)	Investment Expenditure X_1 (YTL)	Overburden Ratio X_2 (m^3/ton)	Number of Personnel X_3 (no)	Amount of Production Sold Y_1 (ton)	Total Income Y_2 (YTL)
Soma	565.487	2705	3.126.311	7,75	3.486	8.148.940	469.330.588
Can	87.741	3000	3.597.108	12,00	534	1.063.179	30.616.618
Yatagan	149.325	2230	2.299.858	4,65	1.102	4.352.428	113.607.077
Milas	291.626	1955	1.089.855	4,82	639	4.573.599	86.894.395
Tavsanli	298.652	2330	1.958.862	13,00	3.171	3.369.396	241.023.209
Ilgin	373.254	2776	665.442	4,60	197	259.748	12.560.145
Seyitomer	161.266	1840	775.088	2,34	1.158	5.807.389	134.750.502
Orhaneli	104.846	2200	820.695	5,70	684	187.573	30.399.004

Table 6. Modified Fried-Lovell results

Enterprises	*Slacks in the 1st Stage*					*Efficiency in the 1st Stage (θ_k)*
	s_r^-		s_i^+			
	Production Sold	Total Income	Investment	Overburden	Personnel	
Soma	0	0	0	0	0	1,000
Can	244443	0	1281721	2,19	0	0,570
Yatagan	802349	0	899724	0	0	0,823
Milas	0	0	0	0	0	1,000
Tavsanli	3181740	0	0	6,05	566	0,777
Ilgin	0	0	0	0	0	1,000
Seyitomer	0	0	0	0	0	1,000
Orhaneli	882088	0	0	0,46	231	0,830
				Average Efficiency		**0.875**

Enterprises	*Target Slacks in the 2nd Stage*					*Efficiency in the 3rd Stage (θ_k)*
	Production Sold	Total Income	Investment	Overburden	Personnel	
Soma	0	0	0	0	0	1,000
Can	0	0	0	0	0	0,570
Yatagan	0	0	1323354	0	169	1,000
Milas	0	0	0	0	0	1,000
Tavsanli	0	0	0	1,79	731	0,901
Ilgin	0	0	0	0	0	1,000
Seyitomer	0	0	0	0	0	1,000
Orhaneli	0	0	0	0,06	80	0,912
				Average Efficiency		**0.923**

3.2. Analysis of the Model

In the first stage of the three-stage DEA model, information about slack variables (the outputs not produced in sufficient amount and the inputs used in excess) was collected in the DEA carried out by taking three controllable inputs and two outputs into consideration. As can be seen in the first part of Table 6, it was determined that four DMUs (Soma, Milas, Ilgin and Seyitomer) were technically efficient as only these DMUs met the required conditions (that is, θ_k efficiency values are equal to 1 and the slacks are equal to zero).

In the second stage, a new DEA that would minimize the slacks obtained in the first stage under the influence of non-controllable factors was carried out. As a result of the analysis, minimum slacks in variables according to non-controllable input values were obtained. If the target slacks obtained in this stage are zero, it indicates that the slacks detected in the first stage are completely due to technical inefficiency. If their values are positive, it is concluded that the slacks here are due to non-controllable inputs. The calculated targets for each variable are presented in Table 6.

5 enterprises with null target slack values for five variables were obtained. Four of these enterprises had already been detected as efficient in the first stage. The slacks

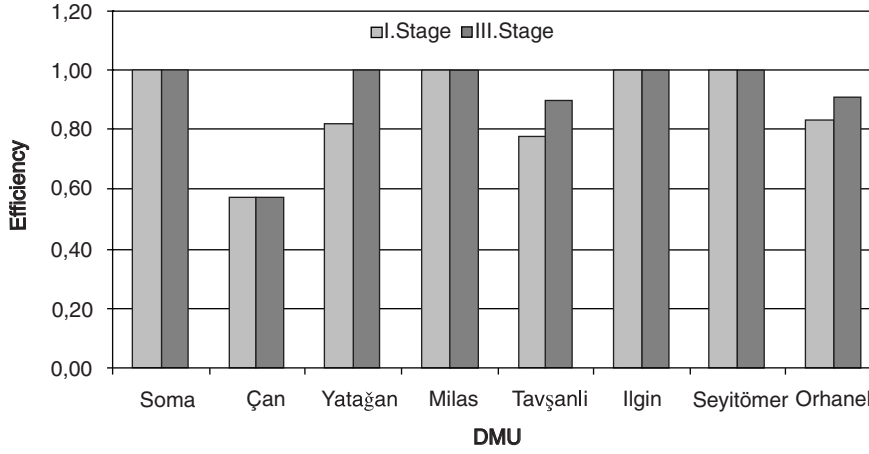

Figure 4. Graphical illustration of the results from 1st stage and 3rd stage.

obtained in the first stage for the one remaining enterprise (Can) indicate that the inefficiency of this enterprise is due to technical inefficiency because all of the target slacks according to non-controllable inputs are null.

As can be seen in the result of the analysis, Can enterprise is really technically inefficient. This has several reasons. First of all, a limitation had been introduced on the use of this coal in large-scale settlement areas due to the high sulphur value it possesses. Founding a thermal power plant was taken into agenda in order to solve this problem. The existing engine park needs to be improved and infrastructure facilities need to be increased since the production capacity of the enterprise will be upgraded to 2.300.000 ton/year, which was 500.000 ton/year for the power plant at the constructing phase in 2005.

Second, there always occur landslides due to the reasons such as the characteristics of Can Enterprise site formation, water problem and that a rapid production cannot be realised because of the failure to achieve the desired development. In order for the overburden stripping and production activities of an enterprise in an area with a high occurrence of landslides to be performed in a rapid and systematic way, improving the existing engine park, expanding the limited site for waste earth, improving the streams surrounding the enterprise and providing sufficient labour will be of most help. Ensuring operational continuity with only overburden stripping without making investments because of landslides is not considered to be likely in this enterprise.

The target slacks of the rest of the three enterprises (Yatagan, Tavsanli and Orhaneli) either increased or decreased due to the effect of non-controllable inputs. When the target slacks for each variable are examined, it is seen that outputs are not practically influenced by non-controllable inputs but inputs are.

In the third stage, the original model was modified so that the negative effects of the non-controllable variables on the enterprises could be compensated. The targets obtained in the second stage were used in the modification process. The adjusted

Table 7. Statistical Comparison between the 1st stage and the 3rd stage

	1st Stage	3rd Stage
No. of efficient enterprises	4	5
% of efficient enterprises	50	62,5
Standard Deviation	0,16	0,15
Average efficiency of inefficient enterprises	0,75	0,79
Average efficiency of total enterprises	0,875	0,923

input values were reached by subtracting the slack values to compensate for the effects of non-controllable inputs from the original inputs (or adding them to the outputs). The new efficiency results were reached with the DEA carried out with this data. The latest efficiency indices are given in Table 6. When the results obtained are examined, it could be suggested that the three DMUs (Yatagan, Tavsanli and Orhaneli) might be harmed in the case that non-controllable variables are not taken into consideration.

The comparison between the results from the 1st Stage, where non-controllable inputs are ignored, and the 3rd Stage, where the adjusted data as a result of determining the effect of non-controllable inputs is used, is presented in Figure 4 and Table 7 and the overall increase in the efficiency of the examined producers is illustrated.

The effect of non-controllable inputs is compensated in terms of both the number of efficient enterprises and the average efficiency percentage. Thus, the adjustments over the efficiency index do not display the same amount of effect on all the enterprises. The coal reserve and low heat value of each enterprise is relatively effective in this adjustment.

It could be suggested that the inefficiency of Can Enterprise (with 57% efficiency score) is completely due to its technical inefficiency and that the slack variables obtained from the evaluations carried out after the slacks corresponding to the effects of non-controllable inputs were cancelled in the third stage (like in Tavsanli and Orhaneli) are due to technical inefficiency.

As result of the analyses, it was determined that more than half of the Turkish coal enterprises operated efficiently. The common features of the efficient enterprises were identified from the 2005 activity reports of Turkey Coal Enterprises.

The import coal entering the country with a low tax and environmentalist pressures affect our local coal mining negatively. Regarding the results gained, it is apparent that the efficient coal mining enterprises can sell all of the coal they produce. While Soma, Yataian, Milas, Seyitömer enterprises sell all or most of their production to thermoelectric power plant, Ilgin enterprise meets the need of the region. It was also determined that these enterprises did not need to perform too much overburden stripping in order to produce 1-ton coal. The fact that the main overburden stripping activity in Ilgin enterprise came to an end is the most significant reason why this enterprise became efficient. It was observed that the overburden stripping activities were undertaken by a contractor as well as the enterprise. On the other hand, the fact that Çan enterprise has a contractor perform most of the overburden stripping activities result in inefficiency (www.tki.gov.tr/faal_2005.pdf).

Table 8. Reference sets and values for technically inefficient enterprises

Enterprises	Efficiency	Reference Set	Dual Values of the Years in Reference Sets λ (In order of Sets)	
Soma	1,000	*	*	*
Can	0,570	Milas, Ilgin	0,243	0,757
Yatagan	1,000	*	*	*
Milas	1,000	*	*	*
Tavsanli	0,901	Soma, Seyitomer	0,318	0,682
Ilgin	1,000	*	*	*
Seyitomer	1,000	*	*	*
Orhaneli	0,912	Ilgin, Seyitomer	0,854	0,146

It is possible to carry out sensitivity analysis to calculate the right input amount needed to be used by the enterprises still inefficient after being made free of the effects non-discretionary variables.

3.3. Sensitivity Analysis

The DMUs on the enveloped surface (efficient enterprises) consist the reference set for the inefficient units. As a result of the sensitivity analysis performed according to these reference DMUs, the input values needed to be used by inefficient enterprises to become efficient are determined. It is anticipated that the units will reach the technical efficiency if they use these suggested inputs (Table 8).

$$X_{ik}^{*} = \sum_{j \in \Re_k} X_{ij} \cdot \lambda_{jk} \qquad (i = 1, 2, 3, \ldots\ldots, m)$$

X_{ik}^{*} the new i input calculated for inefficient k enterprise,

X_{ij} the amount of inputs for efficient j enterprise in the reference set,

λ_{jk} the dual value of efficient j enterprise in the reference set of inefficient k enterprise.

The enterprises will be able to become efficient when they use the new input values given in Table 9.

As mentioned above, Çan enterprise operates inefficiently due to the high ratio of the coal it produces and frequent landslides. In order for the overburden stripping and production activities to be realized in a systematic and rapid way, the inputs used unsuitably and extensively will be reduced by means of proper structuring and the efficiency of the enterprise will be able to be increased.

Beginning from the year 2005, the activities aimed at making the underground production systems in Tavsanli enterprise fully-mechanized were accelerated. The expected decrease in production costs and increase in productivity in comparison with the traditional production system couldn't be achieved through the mechanized production systems. The major reason why the expected results couldn't be achieved although all conditions in terms of technology, labor and financial resources emerged

Table 9. The new input values the inefficient enterprises should use to become efficient

Inputs	Previous	New
CAN		
Investment	3597108	767301
Overburden	12,00	4,65
Personnel	534	303
TAVSANLI		
Investment	1958862	1522777
Overburden	13	4,06
Personnel	3171	1898
ORHANELI		
Investment	820695	681450
Overburden	5,70	4,27
Personnel	684	337

is that a proper administrative and technical structure did not exist. With the proper restructuring, the input amounts will be reduced and the enterprise made efficient.

Due to the construction of Orhaneli Thermoelectric Power Plant Chimney Gases Treatment Facility, the production of the mining enterprise went down for a long time. As a result of this, the enterprise was operated at loss and it couldn't afford even its own renovation investments. Besides, the prolonged waiting period about the transfer of the mine and the plant with a "Build-Run-Transfer Law" and the chronic overburden stripping, production, employment and planning deficiencies caused new uncertainties. Therefore, in these uncertain conditions, dragline panels couldn't be prepared and run. All these negative effects influenced the enterprise efficiency (SPO, 2001).

4. CONCLUSION

In the efficiency measurement employing three-stage DEA, the basic distinction between the effects not under the control of the producers and the proper technical inefficiency component can be made. The accurate measurement of the technical efficiency for each producer can be performed by means of the analysis carried out in this way and therefore prospective strategies according to corrected results from the enterprises can be determined. The fact that DEA is used in every stage of this model and it doesn't require a functional form like in parametric methods makes it possible to avoid any calculation mistakes that might be caused by the fact that this production function is not known in practice.

It was observed as a result of the analyses that the average efficiency value went up from 87,5 percent to 92,3 percent. 5 enterprises (Soma, Milas, Ilgin and Seyitömer) out of 8 examined were determined to be efficient. The common feature of the efficient enterprises is that they can sell all of their production and their overburden stripping costs are low. It was also determined that the inefficiency in Çan enterprise is caused

by technical inefficiency only; the one in Yataǧann is caused by non-discretionary inputs only; those in Tavsanli and Orhaneli, on the other hand, are caused by both technical inefficiency and non-discretionary inputs.

Both the sulfur value of the coal and site formations were influential in the technical inefficiency of Çan enterprise.

The reserve for mine deposits, considered among non-discretionary factors, has a key role in determining the investments to be made. The usage duration of the investments and equipment should suit the amount of the reserve and the span of the mine. The low heat value is another factor which is one of the quality parameters playing a key role in determining the coal price. It was determined by means of analysis results that non-discretionary factors such as reserve and low heat value have effects on the efficiency. It was determined that the inputs used are too many in comparison with reserve values in Yatagan and Tavsanli enterprises where non-discretionary factors are effective and that the inputs used are too many when compared with the production amount sold because the low heat value of the coal produced is low in Orhaneli enterprise. Tavsanli and Orhaneli enterprises determined to be inefficient still after excluding the effects of non-discretionary inputs from discretionary inputs were also identified to be technically inefficient. The technical inefficiency is caused by the lack of proper administrative and technical structuring.

It was concluded that in order for the accurate technical inefficiency values of mining enterprises to be determined, non-discretionary inputs should certainly be taken into consideration in efficiency calculations.

A sensitivity analysis was conducted so that suggestions could be made to eliminate the technical efficiency observed after adjusting the negative effects of non-controllable variables on the enterprises. As a result of the analysis, the input values which the enterprises should use in order to become technically efficient were determined.

REFERENCES

Atan, M., 2005. Üretim ve Verimlilik Artirma Teknikleri, *Egitim Notlari*. Gazi Üniversitesi, Ekonometri Bölümü inTurkish.

Balat, M., Ayar G., 2004. Turkey's coal reserves, potential trends and pollution problems of Turkey. *Energy Exploration & Exploitation*, Vol. 22, pp. 71–81.

Banker, R.D., Morey, R.C., 1986. Efficiency Analysis for Exogenously Fixed Inputs and Outputs. *Operations Res*., Vol. 34 (4), 513–521.

Banker, R.D., 1992, Estimation of Returns to Scale Using Data Envelopment Analysis. *European Journal of Operational Research*, Vol. 62, 74–84.

Bosch, N., Pedraja, F., Pandiello, S.J., 2001. The Efficiency of Refuse Collection Services in Spanish Municipalities: Do Non-Controllable Variables Matter, Institut D'Economia de Barcelona.

Byrnes, P., Rolf Fare, Shawna Grosskopf, and Knox Lovell, C.A., 1988. The effect of unions on productivity: U.S. surface mining of coal. Management Science 34, (9): 1037–1053.

Byrnes, P., and Rolf Fare. 1987. Surface mining of coal: Efficiency of US interior mines. *Applied Economics* 19, 1665–1673.

Cooper, W., Seiford, L., Tone, K., 2000. Data Envelopment Analysis: A Comprehensive Text with Models, Applications, References and DEA-Solver Software, Kluwer Academic Publishers.

Farrel, M.J., 1957. The Measurement of Productivity Efficiency, *Journal of The Royal Statistical Society*, 120:253–290.

Gokmen, V., Memikoglu, O., Dagli, M., Oz, D., Tuncali, E., 1993. Türkiye Linyit Envanteri. *MTA Publication*, Ankara, p. 356 in Turkish.

Golany, B., Roll, Y., 1993. Some Extension of Techniques to Handle Non-discretionary Factors in Data Envelopment Analysis. *The Journal of Productivity Analysis* 4, 419–432.

Kaya, Y.T., Dogan, E., 2005. Dezenflasyon Sürecinde Türk Bankacilik Sektöründe Etkinligin Gelisimi, Bankacilik Düzenleme Ve Denetleme Kurumu, *ARD Çalisma Raporlari*. In Turkish.

Kiliç, A.M. and Kiliç, Ö., 2006. Overview of Turkey's Coal Necessity, Reserves and Utilization. *Energy Exploration & Exploitation*, Vol. 24, Number, 6 pp. 439–454.

Konuk, A., 1988. Madencilik Yatirim Kararlarinda Risk Analizi ve Sinir Tenör Uygulamasi, *Doktora Tezi*. Anadolu Üniversitesi, Fen Bilimleri Enstitüsü in Turkish.

Kulshrestha, M., Parikh, J.K., 2002. Study of Efficiency and Productivity Growth in Opencast and Underground Coal Mining in India: a DEA Analysis. *Energy Economics* 24, pp. 439–453.

Kural, O., 1999. Round table: Energy security. Proceedings of the Conference on Prospects for Cleaner Fossil Fuels Systems in Sustainable Development: Communicating their Strategic Value in the Euro-Asian Region. *World Energy Council Turkish National Committee*, May 26–29, Ankara, Turkey, pp. 161–164.

MENR, 2005. Ministry of Energy and Natural Resources. *Energy Report of Turkey*. Ankara, Turkey.

Muniz, M.A., 2002. Separating Managerial Inefficiency and External Conditions in Data Envelopment Analysis. *European Journal of Operational Research*, 143, 625–643.

Muniz, M.A., Paradi, J., Ruggiero, J., Yang, Z., 2006. Evaluating Alternative DEA Models Used to Control for Non-Discretionary Inputs. *Computers & Operations Research*, Volume 33, Issue 5, Pages 1173–1183.

State Planning Organisation (SPO), 2001. Eight Five-Year Development Plan. Mining Special Impression Commission Report. DPT, Ankara, Turkey. Available from: www.maden.org.tr/meslegimiz/oik616.pdf.

State Planning Organisation (SPO), 2004. Eight Five-Year Development Plan. Mining Special Impression Commission Report. DPT, Ankara, Turkey. Available from: www.maden.org.tr/meslegimiz/oik617.pdf.

Syrjanen, M.K., 2004. Non-Discretionary and Discretionary Factors and Scale in Data Envelopment Analysis. *European Journal of Operational Research*, 158 (2004), 20–33.

Tarim, Armagan, 2001. Veri Zarflama Analizi: Matematiksel Programlama Tabanli Göreli Etkinlik Ölçüm Yaklasimi, *Sayistay Yayin Isleri Müdürlügü, Arastirma/Inceleme/Çeviri Dizisi*: 15, Ankara, in Turkish.

Thompson, R.G., P.S. Dharmapala and Robert M. Thrall., 1995. Linked-cone DEA profit ratios and technical efficiency with application to Illinois coal mines. *International Journal of Production Economics*, Volume 39, No:12, Sf: 99–115.

Torrubia, M.J.M., Perez, M.A.M., 2004. Institutes of Secondary Education Versus Arranged School: An Analysis of Productive Efficiency, San Sebastian.

Tuncali, E., Ocakoglu, F., 1995. Türkiye'nin Kömür Potansiyeli, Rezervleri ve 21. *Yüzyilda Kömür. Kömür Teknolojisi ve Kullanimi Semineri III (in Turkish)*, 13–14 Ekim, Yurt Madenciligini Gelistirme Vakfi Yayinlari, Ankara, pp. 19–26.

Yu, C., 1998. The Effects of Exogenous Variable in Efficiency Measurement-A Monte Carlo Study. *European Journal of Operational Research* 105, 569–580.

www.tki.gov.tr/TKI_HAKKINDA/ener_kom.htm.

www.tki.gov.tr/faal_2005.pdf.

WECTNC, 2004, *World Energy Council Turkish National Committee*. Energy report of Turkey in 2003. Ankara, Turkey.

WCI, 2005. *World Coal Institute*. The role of coal as an energy source. 2004, London, UK. Energy. 1994:19; 1235–1244.