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An assessment of mining efficiency in Turkish lignite industry

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ABSTRACT

This article focuses on the mining activities of Turkish Coal Enterprises (TKI), the major lignite supplier in Turkey. First, we analyzed the lignite production and overburden removal activities of TKI from a historical perspective and then employed the Principle Component Analysis to build a mining efficiency index of TKI and investigated its historical development since the establishment of the company. We found that labor productivity and operational structure have been the most important factors, positively affecting the index. The current article makes two important contributions: (1) by using the most comprehensive data set available on TKI for the first time, and (2) by developing a Mining Efficiency Index (MEI), which can be used to analyze productivity in lignite mining activities in different countries.

Introduction

Coal has always been an important fuel in Turkish energy system. After the oil crises in the 1970s, rising concerns about energy supply security boosted the significance of coal as a domestic source in Turkey similar to other energy import-dependent countries. Its share in overall energy consumption increased from 24.7% in 1970 to 30.9% in 1986 and then fluctuated between a low of 26.5% (in 2001 and 2005) and a high of 33.7% (in 2012).

Furthermore, the share of lignite in primary energy consumption (PEC) first increased progressively to 20.9% in 1986 and then declined to 10.2% in 2005, forming a major trough. Since then it has increased again, reaching a share of 14% in 2012. On the other hand, the share of hard coal in PEC increased steadily from 8.8% in 1978 to 16.7% in 2012. From 1977 until 2003, the share of lignite was larger than that of hard coal, yet from 2003 to 2012, Turkey consumed a total of 147.581 million tons-of-oil-equivalent (toe) of hard coal and 132.274 million toe of lignite.

The increasing share of hard coal relative to that of lignite emphasizes the growing role of hard coal in the Turkish energy system. However, this generates an important threat to the energy supply security of the country because the hard coal supply is mostly import dependent and energy import dependency is a major problem in Turkey. In 2012, Turkey consumed 120.093 million toe primary energy of which only 25.8% (31.964 million toe) was produced domestically, 98.693 million toe was imported, and 6.866 million toe was exported, thus net import dependency on foreign energy sources was 74.2%. The hard coal import increased to 19.237 million toe, comprising 94.7% of the total hard coal consumption in 2012. On the other hand, lignite is the most abundant fossil fuel resource in Turkey and demand for it has always been met by domestic production (WEC-TNC, 1986, 1990, 1994, 1997, 2002, 2006; MENR, 2014).

On the production side, since 1976, lignite has ranked first among other energy sources (Fig. 1). Since then it increased with minor fluctuations until its local peak in 1998. Between 1998 and 2004, it decreased by 28.5% from 12.792 million toe to 9.141 million toe and then increased again to 17.860 million toe in 2012. On the other hand, hard coal production has witnessed a continuous decrease. The same is true for oil production with the exception of the 1985–1991 period. Natural gas and asphaltite production has been minimal compared to other fossil fuels with maximum productions of 931 and 567 thousand toe, respectively.

Historic lignite production and total primary energy production (PEP) are represented in Fig. 2. The two trends are parallel to each other with a correlation coefficient of 0.98. This means that PEP has mostly been driven by lignite production, whose share increased from 11.9% in 1970 to 55.0% in 2012. Therefore, lignite

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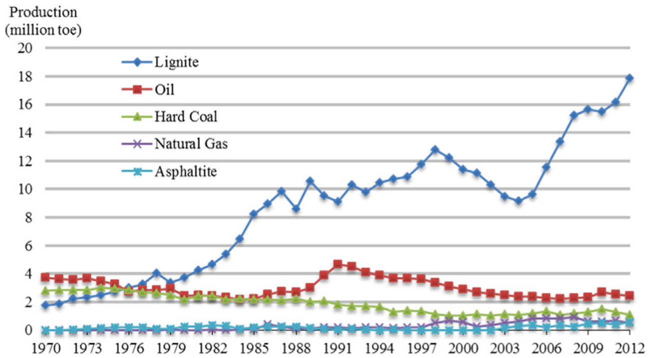

Fig. 1. Primary energy production for Turkey by energy source, 1970–2012. *Source*: WEC-TNC (1986, 1990, 1994, 1997, 2002, 2006); MENR (2014).

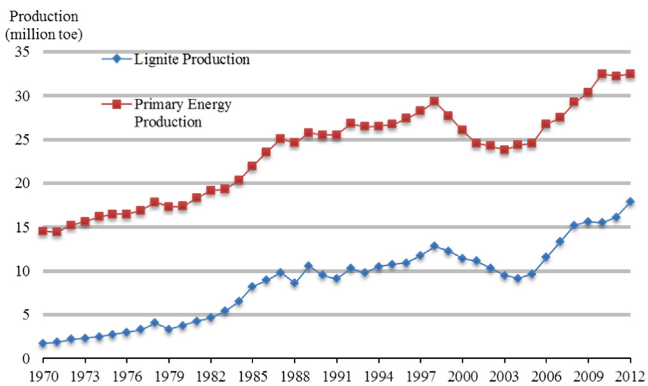

Fig. 2. Lignite production/consumption and total primary energy production, 1970–2012. *Source*: WEC-TNC (1986, 1990, 1994, 1997, 2002, 2006); MENR (2014).

as a major domestic energy source in the Turkish energy mix will be of significant importance for decreasing the burden of energy import dependence, and its share of PEC should be increased from the current value of 14.8% through an emphasis on the exploration and production. Yet, it is well known that lignites emit much higher GHGs (Greenhouse Gases) compared to other fossil fuels and their improper use causes severe local and global environmental degradation. The authors of this article are of the opinion that domestic lignites have a significant role to play in the energy systems of countries, such as Turkey, which are energy import dependent, provided that they are used in an environment-friendly manner by employing Clean Coal Technologies (CCT).

In Turkey, the exploration and production sector of the lignite industry is dominated by state-owned companies such as the General Directorate of Mineral Research and Exploration (MTA), the General Directorate of Turkish Coal Enterprises (TKI), and the Electricity Generation Company (EUAS). While MTA is a governmental institution established to conduct reconnaissance, appraisal, and exploration of coals among other minerals, TKI and EUAS are responsible for lignite production and electricity generation, respectively. Since it was established in 1935 MTA has been involved in various activities in the Turkish lignite industry such as geological mapping, geochemical analyses, geophysical studies, and exploratory drilling. With the establishment of TKI in 1957, some of these activities were transferred to TKI. TKI was initially responsible for all types of coal deposits of Turkey but later hard coals were transferred to Turkish Hard Coal Enterprises (TTK) after its establishment in 1983 (Ediger et al., 2014).

From 1957 to 2010, the majority of lignite production in Turkey was carried out by TKI, such that it was responsible for 73% of lignite produced. However, the share of the private sector and other public companies in lignite production decreased to 42.6% in 2010 from 84.3% in 1984. As a result of the step-by-step transferring of the lignite fields feeding coal-fired power plants to EUAS between 1989 and 2000 (such as Kangal in 1989, Elbistan in 1995, and Cayirhan in 2000), EUAS became the second largest lignite producer in Turkey after TKI. By 2010, EUAS was the public company with the largest lignite reserves in Turkey. EUAS was formed in 2001 when the Turkish Electricity Generation and Transmission Company (TEAS) was divided into three separate entities, each responsible for electricity generation, transmission, and trading.

This study focuses on TKI's mining activities given that it has been the major lignite supplier since 1957. The data used in this study is taken from Ediger (2014) unless otherwise stated. Firstly, we analyzed mining activities of TKI from a historical perspective and then we built a mining efficiency index of TKI and investigated how efficiently the company had operated since its establishment. Finally, we have concluded that labor productivity and operational structure have been the most important factors affecting the efficiency index. Although TKI's operational efficiency has increased significantly over time, this trend was severely disrupted in 2002–2003, possibly as a delayed response to the economic crisis Turkey experienced in 2001. The current article makes two important contributions: (1) by employing the most comprehensive data set on TKI for the first time, and (2) by developing a mining efficiency index for TKI, Turkey's major lignite supplier.

The structure of this article is as follows: *TKI's lignite production* reviews TKI's historical lignite production while providing detailed explanations of production by its enterprises and fields; *Overburden removal* analyzes overburden removal activities carried out in TKI fields; *Mining efficiency index* is dedicated to the analysis of the historical efficiency of TKI's exploration and production activities; and *Conclusions and policy implication*, finally, concludes with policy suggestions.

TKI's lignite production

Corporation's overall production

Turkey's cumulative coal production between 1957 and 2010 was 1853 million tonnes of which 89% (1649.3 million tonnes) was lignite, 10.2% (188.4 million tonnes) was hard coal, and only 0.8% (15.6 million tonnes) was asphaltite. During the same period, TKI was responsible for a cumulative 1425 million tonnes of coal of which 1245 million tonnes were lignite and 180 million tonnes hard coal.[1] Approximately 75% of Turkey's cumulative lignite production in the same period was carried out by TKI. As shown in Fig. 3, TKI's run-of-mine lignite production curve increased to 45.7 million tonnes and reached its peak in 1994. After this high, two other significant peaks in 2000 and 2008 were reached between 1995 and 2004, and 2004 and 2010 with values of 43.0 million tonnes and 45.9 million tonnes, respectively.

The peak of 2008 is the historic high point of TKI's run-of-mine lignite production. The company's salable production in this horizon followed a path that is parallel to the run-of-mine production and both curves got closer in some periods. For instance, in 1957 only 23.7% of run-of-mine lignite production was salable, this ratio gradually increased up to 90.8% in 1981. It remained above 90% until 2002, yet after 2003 it declined falling to 74.4% in 2010. In aggregate, 85% of 1.42 billion tonnes of run-of-mine production were supplied as salable production between 1957 and 2010.

[1] Please note that TKI also produced hard coal until TTK was established in 1983.

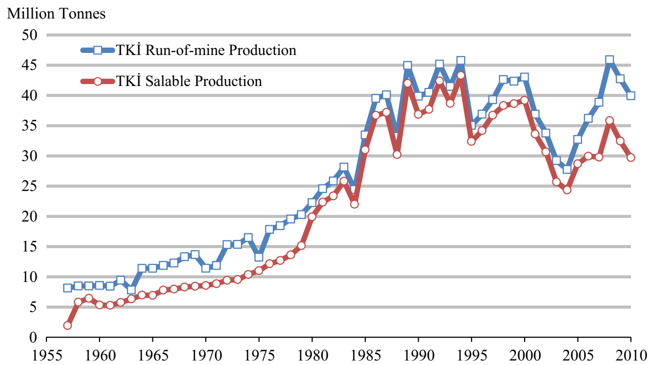

Fig. 3. TKI's run-of-mine and salable lignite production, 1957–2010.

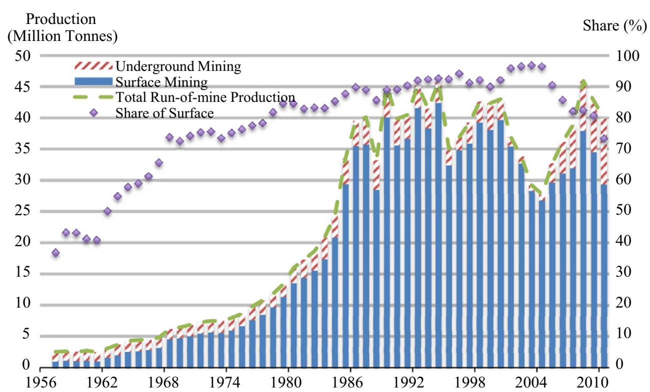

Fig. 4. Production in surface and underground mines and share of surface production in total, 1957–2010.

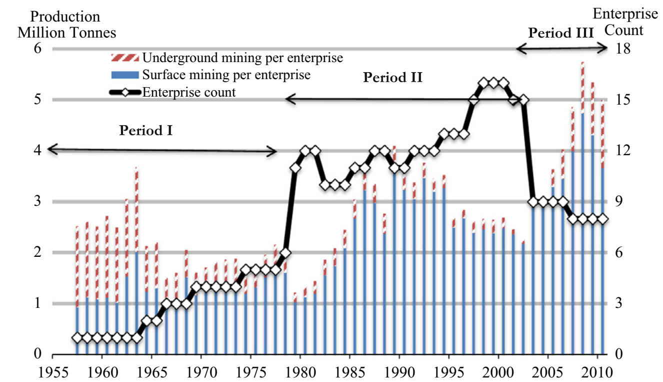

Fig. 5. TKI's enterprise numbers and surface and underground lignite production per enterprise, 1957–2010.

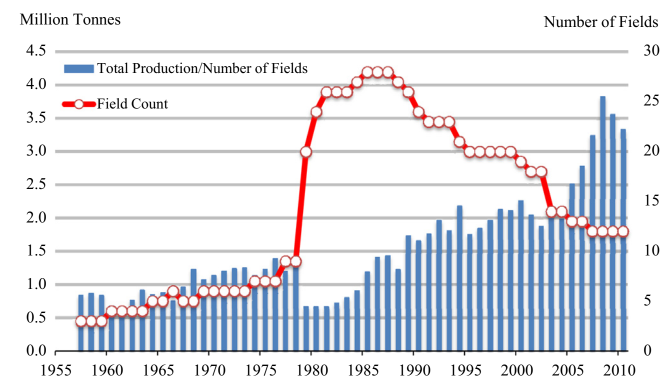

Fig. 6. Number of fields and average productions, 1957–2010.

Around 87% of TKI's cumulative run-of-mine lignite production comes from surface mines while the share of underground mines was only 13% (Fig. 4)[2]. The share of surface production increased steadily from 36.8% in 1957 to 96.9% in 2003 and then decreased to 73.3% in 2010. Moreover, in absolute values, underground mining first increased from 1.5 million tonnes in 1957 to 4.9 million tonnes forming a peak in 1989, and then it decreased to its historic low of 0.9 million tonnes in 2003 with an occasional peak at 4.2 million tonnes in 1999. The surface production curve, on the other hand, is very similar to the run-of-mine production curve. In 2010, the surface and underground productions were 29.28 and 10.65 million tonnes, respectively.

It is noteworthy that a trend reversal both in real values and in the share of underground lignite production occurred in 2002. As a result of governmental policies, the underground lignite production increased 11.6 times from 0.91 million tonnes in 2003 to 10.65 million tonnes in 2010.

Production in enterprises

Since it was established in 1957, 20 different enterprises have participated in the production activities of TKI. The average operation life of these enterprises is 21.48 years while the average annual and average cumulative productions are 2.35 million tonnes and 62.27 million tonnes, respectively. The largest two enterprises, GLİ (29.91%) and ELİ (23.05%), are responsible for more than 50% of TKI's cumulative lignite production, which is 1.245 billion tonnes.

The relationship between TKI's lignite production and the number of enterprises is illustrated in Fig. 5. Lignite production per enterprise shows three cyclical periods between 1957 and 1978, 1979 and 2002, and 2003 and 2010, with peaks in 1963 (3.363 million tonnes), 1989 (4.09 million tonnes), and 2008 (5.74 million tonnes). These periods also correspond with changes in enterprise numbers: The number of enterprises rose gradually from 1 to 6 in Period 1, with some fluctuations from 11 to 15 in Period 2 and decreased slightly from 9 to 8 in Period 3. The maximum number of enterprises occurred with a value of 16 in the three years between 1998 and 2000.

The two biggest changes in the number of TKI enterprises occurred as an increase from 6 to 11 between 1978 and 1979 and as a drop from 15 to 9 between 2002 and 2003. These major changes, which occurred at the beginning of the second and third periods, appear to be related with changes in the local administrative/operational structure of the company. However, it is interesting to note that both the rise and drop in number of enterprises affected the production per enterprise positively. This may be explained by the fact that increasing the number of enterprises without putting new coalfields into operation negatively affects the overall productivity of coal production.

Similar explanations are also true for the different periods. The increasing number of enterprises in Period I did not lead to a production increase while the decreasing number of enterprises in Period III did. In Period II, however, a production increase until 1989 and decrease after 1989 is recorded as number of enterprises increased. The periods when the production per enterprise significantly changed while the enterprise count remained steady are also related with productivity. Two apparent examples are the periods between 1998 and 2000, when the production decreased, and between 2007 and 2010, when the production rose. Another notable characteristic is that during the first years of operation (1957–1961) underground production was larger than that of surface mines; yet thereafter surface mining has dominated the production operations of TKI.

[2] In this study, the term "surface mining" is used as synonymous with "open-pit mining".

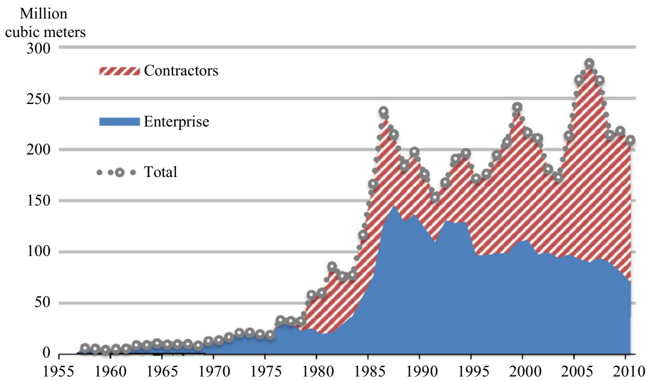

Fig. 7. TKI's overburden removal activity, 1957–2010.

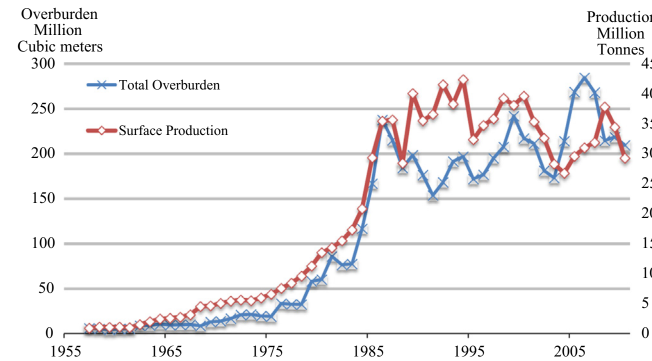

Fig. 8. The relationship between overburden removal and surface production, 1957–2010.

Production in fields

TKI has operated a total of 29 lignite fields in different periods since 1957. The variation in the number of active fields and of total production per field between 1957 and 2010 are given in Fig. 6. As shown in the graph, the number of fields and average production per field grew together gradually with a high correlation until 1978. Production increased from 838.68 thousand tonnes in 1957 to 1.3 million tonnes in 1978 while the number of fields rose from 3 to 9 in the same period. In other words, as more fields were brought into operation production per field increased, indicating that new fields contributed to average production more than the old ones.

However, this situation changed significantly in 1979 when TKI brought 11 new fields into operation. The number of fields later increased to 28 in 1985 and remained the same three years in a row, forming a historical peak before it decreased to 12 between 2007 and 2010. At the same time, the production per field declined sharply to 668.70 thousand tonnes in 1979, and to an all-time low of 665.25 thousand tonnes in 1981, and then increased with some fluctuations until its historic high of 3.82 million tonnes in 2008. Since then production has again decreased. In this period, the number of fields in general correlates negatively with production as a result of the closing of unproductive fields as these fields matured over time. It is also interesting to note that the average production decreased as the number of fields remained the same between 2007 and 2010.

Overburden removal

Overburden removal in surface coal mines is the activity of moving the overburden layers above the coal seams and it is generally practiced when the seam is close enough to the surface. The amount of overburden removal activity and technics adopted vary according to the geological properties of the overburden rock and the coal seam as well as projected life and production of the field, and finally economical and technical feasibility calculations (Merritt, 1986).

In the lignite fields of TKI, overburden removal has been carried out by either the corresponding enterprise or by third-party contractor firms (Fig. 7). Since its establishment in 1957, the cumulative overburden amount of TKI is 6.14 billion cubic meters of which 53% is done by enterprises amounting to 3.25 billion cubic meters and 47% is by contractor firms amounting to 2.89 billion cubic meters.

The total overburden amount increased slightly from 6.08 million cubic meters in 1957 to 19.20 million cubic meters in 1975. It then began to increase exponentially with the contribution of third-party contractor firms, peaking in 1986 with a value of 237.82 million cubic meters of which 46.3% was held by contractors. It finally reached its all-time high in 2006 with a value of 284.79 million cubic meters after some fluctuations. In the post-1976 period, although enterprises conducted most of the overburden removal, contractors became dominant between 1979 and 1985 with a maximum share of 75.34% in 1981. During the 1985–1992 period, the share of enterprises increased gradually reaching a share of 77.84% in 1992. The continuously increasing share of contractors' after 1986 is partly related to the privatization policies implemented in energy sectors such that the share of contractor firms increased from 22.16% in 1992 to 68.38% in 2006. Finally, from 2006 to 2010, total overburden amount decreased to 209.61 million cubic meters of which 33.47% was by enterprises and 66.53% by contractors. This latest decreasing trend in total overburden amount can be attributed to increasing underground mining operations.

By definition, there exists a significant relationship between surface production and overburden amount with one or two years lag in between (Fig. 8). Both curves increase exponentially from 1957 to 1986 in overburden and to 1987 in surface production. Similarly, the peaks occur in 1999 in overburden and in 2000 in surface production. Finally, the latest peaks occur in 2006 in overburden and 2008 in surface production. The relationship between overburden and surface production is seen clearly in the 2006 and 2008 peaks.

The cumulative surface production and overburden as well as strip ratio (SR)[3] of TKI's fields are summarized in Table 1. Overall, cumulative amounts of surface production and overburden removal are 1.08 billion tonnes and 6.14 billion cubic meters, respectively. The cumulative SR, which indicates overburden removal efficiency, is 0.17 t/cubic meter. The largest three fields of cumulative surface productions are Seyitömer (21.70%), Tuncbilek (17.89%), and Soma (14.27%), and of cumulative overburden are Tuncbilek (30.22%), Soma (18.52%), and Seyitömer (8.31%). However, the most efficient fields in terms of strip activity, i.e. with lowest SR, are Seyitömer (2.17 m^3/tonne), Milas (2.69m^3/tonne), Elbistan (3.02 m^3/tonne), Ilgin and Yatagan–Eskihisar (4.08 m^3/tonne), Denis (4.98 m^3/tonne), and Tinaz–Bagyaka (5.42 m^3/tonne).

The historical development of TKI's overall strip efficiency[4] is given in Fig. 9. From 1957–1968, it rose from 0.15 t/cubic meter in 1957 to 0.52 t/cubic meter, and then fell to 0.14 t/cubic meter in 2010. The reason for the gradual improvement of strip efficiency before 1968 may be related with the dominance of underground mining. On the other hand, the reason for overall worsening in

[3] Strip ratio is defined as the amount of over-burden rock needed to be stripped for production of one unit of ore hence its unit is m^3/tonne.

[4] Here we used an efficiency proxy of strip ratio, i.e. (1/SR), which is the amount of production per one cubic meter of overburden removed; hence its unit is tonne/m^3.

Table 1
Surface production and overburden removal activity in TKI fields, 1957–2010

Field	Cumulative production		Cumulative removal		Strip ratio (m^3/tonne)
	Tonnes	Share in TKI total (%)	Cubic meters	Share in TKI total (%)	
Seyitömer	234,810,989	21.70	510,140,933	8.31	2.17
Tuncbilek	193,677,250	17.89	1,855,652,726	30.22	9.58
Soma	154,411,809	14.27	1,137,188,808	18.52	7.36
Milas	130,259,422	12.04	349,747,062	5.70	2.69
Elbistan	94,101,205	8.69	284,218,023	4.63	3.02
Yatagan-Eskihisar	80,726,301	7.46	329,018,591	5.36	4.08
Denis	57,094,382	5.28	284,429,984	4.63	4.98
Tinaz-Bagyaka	32,314,505	2.99	175,250,234	2.85	5.42
Can	25,181,811	2.33	480,325,766	7.82	19.07
Eynez	22,397,119	2.07	192,268,843	3.13	8.58
Orhaneli	16,774,656	1.55	227,635,047	3.71	13.57
Ilgin	11,819,206	1.09	48,187,708	0.78	4.08
Göynük	5,864,446	0.54	50,780,219	0.83	8.66
Keles	5,827,510	0.54	51,688,771	0.84	8.87
Alpagut	5,308,597	0.49	68,066,777	1.11	12.82
Sirnak	4,730,113	0.44	29,096,039	0.47	6.15
Degirmisaz	1,805,425	0.17	10,327,119	0.17	5.72
Silopi	2,225,538	0.21	18,697,477	0.30	8.40
Saray	2,117,918	0.20	15,431,945	0.25	7.29
Ermenek	275,129	0.03	5,539,371	0.09	20.13
Kangal	207,216	0.02	8,033,034	0.13	38.77
Karliova	152,973	0.01	2,378,523	0.04	15.55
Söke-Aydin	145,000	0.01	4,762,535	0.08	32.85
Ercis	51,904	0.00	971,569	0.02	18.72
Beysehir	33,922	0.00	554,067	0.01	16.33
TKI Total	1,082,314,346	100	6,140,391,171	100	

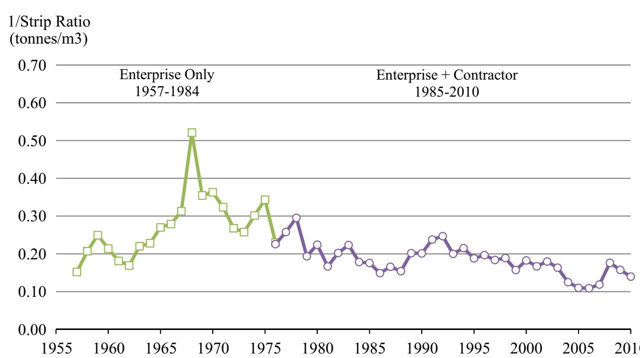

Fig. 9. TKI strip efficiency from 1957–2010.

strip efficiency after 1968 can be attributed to geological constraint; which means an increasing amount of overburden needed to reach the deeper coal seams as lignite mines mature. The increasing share of contractors in total strip can also be considered as one of the factors affecting the strip efficiency.

Mining efficiency index

In this section, we analyze the efficiency of mining activities of TKI by constructing an overall efficiency[5] variable/index using Principle Component Analysis (PCA). Our method is closest to the one applied by Ediger and Berk (2011) which builds a crude oil import vulnerability index. The PCA methodology includes selection of relevant factors and indicators to be included in the index, capturing a correlation matrix, calculating eigenvalues, rotated component loadings using orthogonal rotation matrix, and finally, score coefficients (Ho, 2006).

We used company's data on the following factors to create our index: annual run-of-mine production, capital, labor (both blue and white collar), and overburden (own and total) amount, enterprise and field count over the period from 1957 to 2010. Table 2 provides descriptive statistics of the data. As previously mentioned the data is taken from Ediger (2014).[6] The labor data, which is used in this study, is the annual count of number of personnel employed in different enterprises of TKI. The capital data, moreover, is the current capital stock, which is counted as the cumulative additions to the capital stock in the initial period.

Using the data introduced above we suggest following 8 indicators to be included in the PCA methodology:

$$I_1 = \frac{TKI\ Aggregate\ Production}{Blue\ \ Collar\ \ Labor}$$

$$I_2 = \frac{TKI\ Aggregate\ Production}{White\ Collar\ Labor}$$

$$I_3 = \frac{TKI\ Aggregate\ Production}{Total\ Capital}$$

$$I_4 = TKI\ Enterprise\ Count$$

$$I_5 = TKI\ Field\ Count$$

$$I_6 = \frac{TKI\ Aggregate\ Production}{TKI\ Total\ Overburden}$$

$$I_7 = \frac{TKI\ Own\ Overburden}{TKI\ Total\ Overburden}$$

$$I_8 = Hubbert\ Curve\ Estimated - Actual\ Production$$

It is widely known that the PCA methodology suffers severely from self-selection bias, which arises during the selection of indicators to be included in the index. Therefore, we need to explain the rationale on the inclusion of each and every indicator. First three indicators ($I_1 - I_3$) represent partial productivity measures of input variables appear in the conventional production functions (e.g., Törnqvist, 1936; Solow, 1957; Hannula, 2002).

Moreover, a number of studies take different factors into account when analyzing the productivity in mining industries.[7] For instance, Rittenberg and Manuel (1987) found that increases in the stripping ratio offset the productivity gains in surface coal mining in the USA during 1960s. Similarly, Naples (1998) points out the importance of productivity increases in surface mining and thus in overburden removal activities in the USA during the period between 1940 and 1959. Since most of the lignite production in

[5] Here we use the term "efficiency" instead of commonly used term "productivity" since we include some other factors that are relevant yet do not appear directly in the production function, namely field count, enterprise count, total strip amount and depletion proxy.

[6] The historical set of data in Ediger (2014), moreover, was compiled with the contribution of all of the TKI's headquarter departments and enterprises. For this purpose, a team representing from each relevant department of TKI was assembled. For instance, financial data like capital was compiled by a team member from the Department of Accounting; labor data by a team member from the Department of Human Resources; production and overburden amount data by a team member from the Department of Production, data on chronological changes in corporate structure by a team member from the Department of Research, Planning and Coordination. The team used annual reports of the company as the main source and contacted corresponding enterprises whenever inconsistencies detected.

[7] Please refer to e.g., Sider (1983), Rittenberg and Manuel (1986, 1987), Naples (1998), Garcia, et al. (2001), Kulshreshtha and Parikh (2001, 2002), Stoker et al. (2005), Rodríguez and Arias (2008), Fang, et al. (2009).

Table 2
Summary statistics of variables.

	ln(Lignite prod)	ln(Capital)	ln(Labor)	TKI own strip amount	TKI total strip amount	Enterprise count	Field count
Mean	16.56	10.32	11.99	60266886	1.14E+08	8.555556	14.38
Median	16.93	10.41	11.72	47681552	1.01E+08	9.000000	13.00
Maximum	17.64	11.16	20.72	1.46E+08	2.85E+08	16.00000	28.00
Minimum	14.73	9.02	6.62	4351090	4351090	2.000000	3.00
Std. Dev.	1.013	0.589	4.953	47488322	94725046	4.381	8.627
Skewness	-0.515	-0.670	0.315	0.238239	0.138	-0.018	0.169
Kurtosis	1.763	2.450	1.642	1.456957	1.402	1.800	1.516
Jarque-Bera	5.83*	4.72*	5.04***	5.87*	5.91*	3.24	5.21*
# of observations	54	54	54	54	54	54	54

*represents significance at 10% confidence level.

Turkey during the subjected period occurred in surface mines, it is reasonable to consider strip mining as an important driver in our efficiency index. Thus, we have included I_6 capturing the partial productivity of overburden removal activities. Moreover, we also consider the efficiency gains/losses due to outsourcing this activity. In this regard, I_7 captures the ratio of the overburden amount held by the company itself in total overburden amount.

Without a doubt, the companies in resource industries have some unique characteristics that distinguish them from other sectors. Optimal decision about the production over time highly depends on the resource endowment they have.[8]Golombek et al., (1995), for instance, proposes a cost function for exhaustible resource production which takes the depletion effect into account. According to the authors the cost of producing one additional unit of exhaustible resource increases sharply to infinity as the production capacity is reached. In addition, Rodríguez and Arias (2008) argue that mining productivity is highly dependent on continuous depletion of the exhaustible resource. To this end, we useI_8, a proxy variable for depletion, as depletion of already producing fields may have some impact on lignite production.[9]

There has also been a mass literature on the operational and efficiency differences between state-owned and private companies in the mainstream economics literature.[10] Although the literature does not seem to agree on which is more efficient, both the theoretical and applied works suggest both ownership structures are unique in their own way. There have also been some studies concentrating on the efficiency differences between state owned and private companies extractive resource industries (e.g. Al-Obaidan and Scully, 1991;Bai and Bennington, 2005; Victor, 2007; Wolf, 2009; Eller et al., 2011). To this end, we usedI_4 and I_5, namely enterprise and field counts, as the measurement of change in operational and administrative structure of TKI over the period under investigation. We suggest that the continuous ups and downs in the numbers of enterprises and fields represent an inefficient management of the operational organization. Hence, we assume that these indicators have profound effects on the overall efficiency of the company.

The chosen indicators are further normalized as follows:

$$x_{n,t} = \frac{I_{n,t} - \min(I_{n,T})}{\max(I_{n,T}) - \min(I_{n,T})}$$

for $n: 1, \ldots, 8$, where t and T represent the corresponding year and whole period 1958–2010, respectively.[11]

First, the partial correlation matrix was formed using the following formula:

$$\rho_{(x_i x_j . x_k)} = \frac{\rho_{x_i x_j} - \rho_{x_i x_k}\rho_{x_j x_k}}{\sqrt{1-\rho^2_{x_i x_k}}\sqrt{1-\rho^2_{x_j x_k}}}$$

Where $\rho_{(x_i x_j . x_k)}$ is the partial correlation between x_i and x_j, provided that x_k is the controlling variable.

The correlation coefficient (R) matrix, is then used to calculate the eigenvalues λ_i by solving the following determinantal formula $|R - \lambda I| = 0$, for λ, where, I is the identical matrix. Calculated eigenvalues, variability and cumulative variance explained are provided in Table 3. The rotated component matrix is used to calculate the coefficient of each indicator as follows:

$$\beta_k = \frac{C_{ki}\lambda_i}{\sum_{n=1}^{8}\lambda_n}$$

Where k is from 1 to 8 for each indicator, i is the largest value of component 1 to 4 in each row of Table 4.

We end up with the following mining efficiency index (MEI) equation, with coefficients being the overall weights of normalized indicators during the whole period:

$$MEI = 0.199x_1 + 0.234x_2 + 0.009x_3 + 0.236x_4 + 0.219x_5 + 0.011x_6 + 0.014x_7 + 0.076x_8$$

Obviously the most important indicators are Enterprise count (x_4), White-collar labor productivity (x_2), field count (x_5), Blue-collar labor productivity (x_1) with overall weights of 23.6%, 23.4%, 21.9% and 19.9%, respectively.

The historical development of relative shares of indicators as well as the MEI is shown in Fig. 10. Interestingly, although the depletion proxy (I_8) and strip mining related indicators (I_6 and I_7) do not have a significant role in the overall MEI equation, they dominated the index in the early years of TKI's operational life. The contributions of I_6, I_7 and I_8 to the UEI in 1958 were 3.87%, 19.52% and 63.18%, respectively. The shares of these indicators have declined over the years while the shares of I_1, I_2, I_4, and I_5 have risen. At the end of the period under consideration (2010), the contributions of indicators I_1, I_2, I_3, I_4, I_5, I_6, I_7 and I_8 were 30.13%, 31.9%, 0%, 15.6%, 12.19%, 0.13%, 0.25%, and 9.8%, respectively.

Also, different periods are dominated by different indicators. While the prevailing indicators were I_8 and I_4 between 1958 and 1968, and were I_8 and I_5 between1968 and 1978, the indicators I_4 and I_5 prevail between 1978 and 2000. After 2000, however, a

[8] This property of resource markets have extensively analyzed by the literature on exhaustible resources following Hotelling (1931). Seminal works in this stream of literature are as follows: Solow (1974), Dasgupta and Heal (1974), Stiglitz (1974), Loury (1978), Pindyck (1978).

[9] We use Hubbert's methodology (Hubbert, 1956) of production forecasting for exhaustible resources in order to construct this indicator. We used the difference between expected and actual production because as the actual production exceeds that of expected production, i.e. Hubbert curve, we expect to see depletion effect due to more rapid production.

[10] Please refer to Laffont and Tirole (1993), Perotti (1995), Shirley and Walsh (2000), Megginson and Netter (2001) for extensive literature surveys on the matter.

[11] Note that one year of data is lost during data transformation.

Table 3
Eigenvalues for the correlation matrix of normalized indicators

	λ_1	λ_2	λ_3	λ_4	λ_5	λ_6	λ_7	λ_8
Eigenvalues	4.937	1.764	0.587	0.446	0.140	0.083	0.033	0.009
Variability (%)	61.72	22.05	7.34	5.57	1.75	1.04	0.41	0.11
Cumulative variance explained (%)	61.72	83.77	91.11	96.68	98.44	99.48	99.89	100

Table 4
Rotated component loadings matrix (C).

	Component 1	Component 2	Component 3	Component 4
x_1	0.3218	0.4494	0.4319	−0.1643
x_2	0.3762	0.2946	0.4745	−0.1132
x_3	−0.4306	0.0761	0.1436	−0.0098
x_4	0.3846	−0.2552	0.0819	0.4262
x_5	0.3571	−0.4292	−0.0922	0.1126
x_6	−0.3361	−0.1635	0.6028	0.6156
x_7	−0.4127	−0.0996	0.2196	−0.3563
x_8	−0.1039	0.6477	−0.3753	0.5098

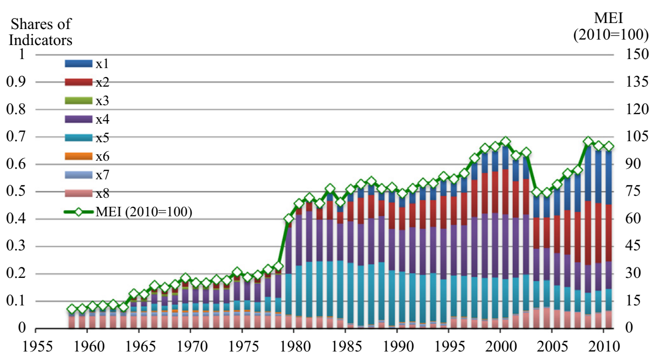

Fig. 10. TKI mining efficiency index (MEI) and relative shares of different indicators, 1958–2010. *Note:* We calculated the MEI using 2010 as a base year (2010 = 100).

significant rise in the dominance of I_1 and $I_2$was observed. The most dramatic changes seem to take place in the contributions of indicators I_4 and I_5, enterprise count and field count. This is expected as these two indicators show more dramatic changes than the others during the relevant period.

In general, the *MEI* is an overall increasing trend during the period under consideration, indicating a continuous improvement in efficiency. However, the entire sequence was interrupted twice during TKI's history. The first one occurred as a considerable jump in improvement between 1978 and 1979 during the end of the second oil crisis. During this period, the world economy as a whole went through a severe oil crisis, which led coal, a more local and evenly distributed resource, to increase its importance in countries' energy policy agendas. TKI, in that period, appears to have conducted appropriate policies to increase the efficiency of its operations.

The second period, which occurred between 2002 and 2003, saw a major worsening in efficiency. This might be related to the 2001 local economic crisis and more importantly to the initiation of market liberalization in the energy sector of Turkey. The market activities were redefined by a series of primary and secondary legislation and brought under the Energy Market Regulatory Administration's (EMRA) regulatory and supervisory jurisdiction, mostly to fulfill the requirements of Turkey's accession to the European Union (EU). The EU's energy acquis discouraged Turkey from using coal to reduce GHG emissions and the production efficiency of TKI, as the state-owned coal company, seems to have been directly affected by these policies. The post 2003 period witnessed an overall improvement in the *MEI*. Although the gradual increase until 2008 slowed down during the last two years, the index by 2010 had increased more than 30%.

Conclusions and policy implications

This article analyzes the mining activities of Turkish Coal Enterprises (TKI). TKI has been the most important lignite supplier in Turkey, providing around 75% of the country's cumulative lignite production. We first examined TKI's production from a historical perspective and then we built a mining efficiency index of TKI by employing the Principle Component Analysis methodology.

The analyses on historical production and overburden removal activities concludes that the decision making in surface mining, which constitutes 87% of TKI's cumulative run-of-mine lignite production, has always been of substantial importance for the company. The efficiency in overburden removal, which by definition has a significant relationship with surface production, has been declining in recent years. Moreover, there have been 20 different enterprises and 29 different lignite fields that participated in the production activities of TKI since it came into existence. This suggests that there have been frequent and drastic changes in the operational structure of the company throughout its history.

In order to analyze through which channels the company can increase its operational efficiency, we developed a mining efficiency ındex (MEI) for TKI. The MEI of the company increased significantly over the subject period, yet its upward trend was interrupted once in 2002 and 2003 due to the country's economic crisis in 2001. In addition, the factors relating to the operational structure and labor productivity have been the most important contributors in the company's operational efficiency. Thus, in order to sustain an increase in efficiency in the long run, the company must increase its labor productivity and pay more attention to its operational structure.

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