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TOTAL SULPHUR DISTRIBUTIONS OF TURKISH LIGNITE DEPOSITS

Summary. Turkey has about 8.4 Gt of lignite reserves of which 3.9 Gt are exploitable. The majority of Turkish lignite deposits are worked in open-pit mines, but there are also some underground operations. Most of the known lignite deposits in Turkey are of low calorific value and have high contents of ash, moisture and total sulphur. Although Çanakkale-Çan lignites have a higher total sulphur content, they are being mined. Generally, total sulphur content varies between 0.93% and 4.25% in important lignite deposits in Turkey. Almost 80% of the total reserves have calorific values below 2500 $kcalkg^{-1}$. The lignites having low calorific values are generally consumed by power plants. The lignites having relatively high calorific values are exploited for household and industry in the country. In this article, lignite reserves which are used as fuel in thermic power plants have been examined.

SIARKA CAŁKOWITA W ZŁOŻACH WĘGLA BRUNATNEGO (LIGNITU) TURCJI

Streszczenie Turcja dysponuje zasobami węgla brunatnego wielkości około 8,4 Gt, z czego zasoby wydobywane stanowią 3,9 Gt. Większość złóż eksploatowana jest odkrywkowo, niektóre sposobem podziemnym. Znaczna część rozpoznanych złóż zawiera węgiel o niskiej wartości opałowej i wysokiej zawartości popiołu, wilgoci i siarki całkowitej. Chociaż węgiel w złożu Çan w prowincji Çanakkale zawiera podwyższoną zawartość siarki całkowitej, jest on eksploatowany. Generalnie zawartość siarki całkowitej w głównych złożach tureckich waha się od 0,93 do 4,25%. Prawie 80% ogółu zasobów stanowi węgiel o wartości opałowej poniżej 2500kcal/kg.
Węgiel brunatny o niskiej wartości opałowej jest powszechnie użytkowany przez elektrownie. Węgiel o względnie wysokiej wartości opałowej jest eksploatowany w kraju na potrzeby gospodarstw domowych i przemysłu. Artykuł traktuje o zasobach węgla, stosowanego jako paliwo w cieplnych elektrowniach.

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Introduction

According to recent studies [4], there are 181 well explored lignite deposits and 98 lignite deposits which require further investigation. Up to now, 8,4 Gt of lignite reserves have been determined in the whole of Turkey. The distribution of lignite deposits in Turkey is such that generally the Eocene lignites are in northern Turkey, Oligocene lignites are in northwestern Turkey, Miocene lignites are in western Turkey, and Pliocene-Pleistocene lignites are in eastern Turkey. Only the Oligocene lignites were formed in a paralic

environment. The rest of the Turkish lignite deposits were deposited in a limnic environment. Total sulphur contents are different in these deposits.

Eocene lignites are located in very limited areas in northern Turkey and were deposited in closed basins. The basement is generally made up of the Palaeozoic or Mesozoic rocks in these deposits. Coal seams are usually between marls. These coals are laterally restricted and usually not thick. There are one or two coal seams between 1-6 m thick. Lignites are bright, brittle and have good quality. Some of these deposits have high total sulphur contents between 1.25 % and 9.60 %. Reserves are small. Total reserve is 176 066 708 tonnes. These lignites generally have been used for domestic heating.

The Oligocene paralic lignites are generally found in northwest Turkey. There are numerous and thin coal seams in these deposits. Total reserve is 217 646 669 tonnes. Reserves are higher than the Eocene lignites, but the qualities are poorer. Total sulphur contents are low and vary between 0.49% and 2.44%. These lignites have been used for domestic heating as well.

Table 1

Characteristics of deposits wchich have thermal power plants of Turkey

Deposits and Sector	Mineable Seam Thickness	Chemical Characteristics In Original Coal				Total Reserves (Tonnes)	Production O:Open-pit U:Underground N:No production
		Moisture (%)	Ash (%)	Total Sulphur (%)	Lower Calorific Value $Kcalkg^{-1}$		
Yatagan Deposit							
Eskihisar Sector	10,15	37,75	18,54	3,15	2241	100282000	O
Turgut Sector	6,20	30,01	24,09	1,01	2583	130000000	U
Bayir Sector	7,23	25,58	24,31	2,77	2671	109063000	U
Tinaz Sector	8,85	32,63	27,16	2,41	2111	41752000	O and U
Bagyaka Sector	13,95	32,50	25,10	2,35	2221	11897000	O
Milas Deposit							
Karacahisar Sector	8,35	28,21	28,06	4,25	2255	85770000	U
Ekizköy Sector	6,74	29,07	22,97	3,42	2284	90982000	N
Sekköy Sector	17.50	33,10	25,77	3,27	1703	83680000	O
Hüsamlar Sector	17,00	39,19	34,15	3,09	1673	88846000	N
Çakıralan Sector	10,61	30,88	34,83	3,45	1549	13795000	N
Alatepe Sector	3,30	21,27	50,14	4,82	1510	10092000	N
Soma Deposit							
Eynez Sector	3,00	15,00	46,54	1,30	2146	308188500	O and U
	3,50	12,24	43,65	1,46	1731		
	15,00	13,41	30,34	1,45	3428		
Merkez Sector	3,50	15,77	33,66	0,93	2761	35176000	O and U
	4,00-9,00	15,87	33,59	0,94	2716		
Î°iklar Sector	7,40	18,36	36,14	-	2408,00	70281000	O and U
	6,15-17,19	12,62	30,00	-	2938		
Tarhala Sector	15,50	18,00	35,00	1,17	3000	25842000	U
Çinge Sector	3,00	30,28	34,06	-	1790	20386125	N
Dualar Sector	2,20	27,00	41,00	2,69	1800	9345577	N
Evciler Sector	2,00	29,00	43,00	1,93	2000	46461000	N

Continuation of Table 1

Deposits and Sector	Mineable Seam Thickness	Chemical Characteristics In Original Coal				Total Reserves (Tonnes)	Production O:Open-pit U:Undergroun d N:No production
		Moisture (%)	Ash (%)	Total Sulphur (%)	Lower Calorific Value Kcalkg^{-1}		
Evciler Sector	8,00	23,00	41,00	1,47	1800		
	5,00	24,00	35,00	3,52	2500		
Deni° I.Sector	6,00-25,00	21,09	39,87	2,20	1824	48476000	O
Deni° II.Sector	6,00-25,00	19,72	45,47	-	1486	103663000	
Kozluören Sector	7,90	17,65	32,15	-	2450	7557000	U
Türkpiyale Sector	3,80	17,32	45,27	-	1638	3216000	N
Beypazari Deposit							
A Sector	2,98	21,71	34,35	4,04	2557	186000000	U
B Sector	2,64	26,44	25,36	2,79	2839	142000000	U
Alt Damar Sector	6,00	14,83	48,70	3,30	1989	62317500	U
Tunçbilek Deposit	7,50	14,35	38,08	2,25	2657	317732000	O and U
		10,65	48,85	1,46	2021		
Seyitömer Deposit	15,00	32,98	31,18	1,21	1900	198666000	O
Orhaneli Deposit							
Burmu Sector	7,45	24,45	22,47	1,83	2482	33900000	O and U
	5,10	21,71	14,46	-	3140		
Çivili Sector	3,00	24,03	42,96	1,96	2134	6110000	O and U
		21,37	37,88	-	2294		
Sagırlar Sector	3,30	21,29	29,57	2,47	2850	6042000	O and U
		25,29	17,97	-	3412		
Af°in Elbistan D.	39,58	50,00	20,00	1,46	1050	3357340000	O
Kangal Deposit							
Kalburçayiri Sector	9,00-10,00	50,00	21,00	2,02	1300	142700000	O
Etyemez Sector	8,00-12,00	49,83	19,04	3,57	1494	30637000	N
Hamal Sector	1,90-15,00	52,09	20,40	2,69	1207	29270000	N
Çan Deposit	16,00	18,21	27,90	4,20	2994	86887000	O and U

The Miocene lignites are generally located in fault bounded basins in western Turkey. Some of the most important Miocene lignites are: Muğla region deposits, Soma, Beypazarı, Seyitömer, Tunçbilek, Orhaneli and Çan deposits (Tab.1). Miocene lignites have high reserve capacities. Total reserve is 2 768 373 780 tonnes. These lignite-bearing formations lie unconformably on basement rocks of the Palaeozoic and Mesozoic. Lignite seams are underlain by a fining-upward sequence of conglomerates, sandstones and siltstones and are overlain by marls, limestones, tuffites and also recent alluvium. Although there are great variations in the lignitic qualities of the region between 1335 kcalkg^{-1} and 4500 kcalkg^{-1}, the Miocene aged lignites are generally good in quality. Lignite seams are few, usually one or two and rarely three, and their mineable thicknesses vary between 1-25 metres. Total sulphur contents are very large and change between 0.50% and 6.51%. The majority of these deposits are worked as open pit mines, although there are also

underground mines in the region. The lignite reserves of the western Turkey, make up 33 % of the total Turkish reserves [2]. These lignites have been used as fuel for thermic power plant, industrial factories and domestic heating.

The Pliocene lignites are generally located in eastern Turkey. The most important Pliocene lignite deposits regions which have thermal power plants are: Afşin-Elbistan and Kangal. Basement is generally Palaeozic or Mesozoic limestones, ophiolotic rocks, recrystallized limestones, metamorphic schists and serpentinites for these deposits. Coal seams are very few, usually one or two. Mineable seams are thick (between 1 m and 40 m, and more than 90 m in Elbistan, Kışlaköy) but there are sterile partings within the seams. Most of these lignites have high moisture and ash contents (25%-53% and 11%-36%), and lower calorific values (1083-2239 $kcalkg^{-1}$). The averages of calorific values are around 1000 $kcalkg^{-1}$. Total sulphur contents are low and vary between 0.5%-3.57%. However, these lignites have usually large reserves. These lignites are generally consumed in power plants. Deposits with low reserves are used for regional domestic heating.

Descriptions of Selected Turkish Lignite Deposits and Total Sulphur Values

In this section, the deposits which have considerable amounts of reserves and as such provide large amounts of fuel for present thermic power plants and are expected to provide fuel for future plants are explained.

Muğla Region Deposits

The lignite-bearing Neogene sediments cover large areas in and around the districts of Yatağan and Milas situated in the province of Muğla in southwest Turkey (Fig.1). Stratigraphically these deposits are very similar. The Kerme Formation lies unconformably on the basement of Palaeozoic gneisses and schists, and Mesozoic marbles. This formation occasionally contains 1-2 m thick lignite seams, but the greater part of them are not economically exploitable, and are not observed in all of the region. The Turgut Formation, which is made up of conglomerates, claystones, siltstones, sandstones and gravelstones, succeeds the Kerme Formation. A lignite seam of 20 m in horizon thickness is placed in between the Turgut Formation at the bottom and the overlying Sekköy Formation. This, in turn, is succeeded by the Yatağan Formation consisting of gravelstones, claystones, sandstones, tuffs, marls and limestones, and by the Milet limestones which are not observed in the whole of the regions. Alluvium overlies the Neogene sediments.

Fig.1. Location map of deposits which have thermal power plants of Turkey
Rys.1. Mapa rozmieszczenia złóż, przy których działają elektrownie cieplne

There is only one seam of 3-17 m mineable thickness. The thick seam has the following average quality. Moisture 19-39 %, ash 18-50 %, and total sulphur 2.35-5.00%, in the original coal, and the calorific value varies from 1434-2671 kcalkg^{-1}. Total reserve is 766 159 000 tonnes (Tab.1). These lignites are generally consumed in power plants. A small part of the reserves are used for regional domestic heating. There are three lignite fired Thermal Power Plants: one with an installed capacity 3x210 MWe in Yatağan, one with 2x210 MWe in Yeniköy, one with 3x210 MWe in Kemerköy.

Soma Deposit

This Miocene deposit is in the district of Soma which is in the north of Manisa Province in western Turkey (Fig.1). Stratigraphically the deposits in the Soma lignite region show similar characterics. The basement is made up of the Paleozoic metamorphic schists and greywackes, and the Mesozoic crystallized limestones. Lignite-bearing Miocene sediments are made up of the units of gravelstones-sandstones-clay, marl and limestones, and lie unconformably over the basement. There are two coal horizons at the base of marl and the middle seam is in the middle-top parts of the limestone. The Pliocene sediments lie unconformably over the Miocene sediments, are made up of coloured clayey sandstone, tuff-marl-agglomerate, gravelstone varved clay and silicified limestone-tuffite [5]. The upper coal seam horizon is present in the coloured clay-sandstone units. The Pliocene units in the region lie unconformably over the older units. These are divided into two units as the claystone-sandstone-gravelstone-tuff-tuffite-limestone and the volcanics at the top. Unconformably overlying the Pliocene sediments are Holocene units which are made up of terrace gravels, alluvium and slope debris. The andesites and basalts cover very large areas in the south and north of the Soma Region.

There are three coal seams in the Soma region. Mineable coal thicknesses vary from deposit to deposit. The bottom, main seam, makes up the major part of mineable deposits in the region, except in the Deniş I and Deniş II sectors, where it is the only upper seam mined. The coal properties are given below for the Soma coal region. Average coal thicknesses vary from 2-25 m. The original coal average moisture is 12-30 %, ash is 30-46%, total sulphur is 0.93-3.52 % and calorific value is 1486-3428 $kcalkg^{-1}$ (Tab.1). Soma region deposits have a total reserve of 678 592 202 tonnes. These lignites are generally consumed in power plants, industrial factories and domestic heating. There are two lignite fired Thermal Power Plants, Soma A with an installed capacity of 2x220 MWe and Soma B (B1, B2, B3, B4, B5 and B6) with an installed capacity of 6x165 MWe.

Beypazarı Deposit

Beypazarı is 100 km northwest of Ankara and contains Miocene lignite deposits (Fig.1). Pre-Neogene rocks are represented by the Palaeozoic metamorphic schists and the Palaeocene-Eocene Kızılbayır Formation in the region. The coal-bearing Çoraklar Formation is made up of the cyclic sequences of sandstones, agglomerates and tuffites. Four formations, which are made up of volcano-sedimentary rock units, above the Çoraklar Formation, are the Hırka Formation, containing bituminous shales and natural soda, the Karadoruk Formation of solely limestones, the Pliocene Softa-1 Formation of sandstones and claystones, and the Softa-2 Formation of chalks and clayey limestones. Pleistocene unconsolidated gravels and the Holocene terrace gravels, slope debris and alluvium overlie the Neogene volcano-sedimentary rocks. Neogene volcanics which were effective from the begining of the Neogene intercalate with all formations. There are two coal seams. The thickness of these seams varies between 2 to 6 metres. The percentages of average moisture, ash, and total sulphur in the original coal are 14-26%, 25-48%, 2.79-4.04% respectively, and calorific value varies from 1989-2839 $kcalkg^{-1}$. The total reserves are 390 317 500 tonnes (Tab.1). There is a lignite fired Thermal Power Plant in Çayırhan, with an installed capacity of 2x150 MWe.

Tunçbilek Deposit

The Miocene Tunçbilek coal region covers large areas in the west and the north of Tavşanlı district belonging to the Kütahya Province (Fig.1). The Domaniç coal-bearing region is placed north of this region. The oldest rocks in the Tunçbilek area which form the basement are the Palaeozoic metamorphic schists and crystallized limestones, and Cretaceous ultrabasic rocks. The basement is unconformably overlain by the Miocene units and the Pliocene units. The Miocene units starts with the compact clastic formations and continues with the clay-marl sequence. The Tunçbilek coal seam is placed in the lower parts of clay-marl sequence. Fresh water limestone and silicic limestone layers are present at the higher levels [6]. The Pliocene is 300 m thick and starts with clastic sediments and gradually passes up to agglomerates and tuffites. The fresh water limestones divide this series, into two parts. Andesitic volcanic rocks overlay tuffs, tuffites and agglomerates and are overlain by basaltic lavas. The Quaternary is made up of slope debris. There is a single Miocene coal seam, which varies between 1-14 m and has several laterally impersistent layers and lenses. The percentages of water, ash and total sulphur in the original coal are 10-14%, 38-48% and 1.46-2.25% respectively, and the calorific value is 2021-2657 $kcalkg^{-1}$. Total reserve is 317 732 000 tonnes in the region (Tab.1). There is a lignite fired Thermal Power

Plant, in Tunçbilek consisting of 3 units with installed capacity of 2x150, 1x65 and 2x35 MWe.

Seyitömer Deposit

This area of Miocene coal is near Seyitömer city in the west of Turkey (Fig.1). The basement of the Seyitömer region is generally made up of serpantinized ultrabasic rocks, radiolarites and crystallized limestones. The Miocene which comes disconcordantly over the basement, starts with the basal conglomerates and sandstones and the main seam comes after the blue green coloured basal clays. The main seam is covered by diatomic clays and marls with bituminous marls, and the top seam overlies these claystone and marls. The Pliocene comes concordantly over the top seam, and seam horizon, starts with marl, tuffite and limestone [6]. The youngest unit is alluvium in the region. The top seam does not have a mineable thickness. The bottom seam averages 16 m mineable thickness. The percentages of water, ash and total sulphur in the original coal are 33%, 31% and 1.21 % respectively, having a calorific value of 1900 $kcalkg^{-1}$. The total reserve has been obtained estimated to be 198 666 000 tonnes in the Seyitömer region (Tab.1). There is a lignite fired Thermal Power Plant, with an installed capacity of 3x150 and 1x150 MWe.

Orhaneli Deposit

The sectors of Burmu show similar stratigraphic sequences at the northwest of Orhaneli in the Province of Bursa (Fig.1). The pre-Neogene rocks are made up of schist, marbles and ophiolites. The Neogene formations are formed from detrital rocks into basal conglomerates, coaly marl and tuffites at the base, and the volcanic rocks of tuffs and lava flows at the top. The post-Neogene sediments are The Pleistocene gravels and alluvium of the valley fill. The coal is hard and differs in quality from sector to sectors and Miocene in age. It is also represented as one seam. In the sectors which are exploited by open-pit minig, the percentages of water, ash, total sulphur in the original coal vary between 21-24%, 22-43%, 1.83%-2.47% respectively, and the calorific value varies between 2134-2850 $kcalkg^{-1}$. In the sectors which have underground mining, water percentage, ash in the original coal varies between in 21-25%, ash between 14-37% and the calorific value between 2294-3412 $kcalkg^{-1}$(Tab.1). The total reserve is 45 052 000 tons. There is a lignite fired Thermal Power Plant, with an installed capacity of 1x210 MWe.

Afşin-Elbistan Deposit

The Pliocene Afşin-Elbistan lignite deposit is located at southeastern Turkey (Fig.1). This deposit is the biggest in Turkey and it covers 120 km^2. The Pre-Neogene basement consists of Permocarboniferous limestones, Eocene limestones and ophiolites. Neogene sediments are limnic in character and the sediments below the coal are made up of claystone, marls, and gravelstone. Freshwater limestones and Post-Neogene formations about 80 m thick consist of gravels and sandstones overlie the coal bearing formations. Coal thickness is at minumum 4 m, and at maximum 90 m, with an average of 40 m. Coal is as close as 10 m to the surface and reaches a maximum of 150 m, averaging 50 m. The percantages of water, ash and total sulphur in the original coal are 50%, 20 % and 1.46 %, respectively, and the calorific value averages 1050 $kcalkg^{-1}$. There are 3 357 340 000 tonnes of total reserves (Tab.1). Afşin-Elbistan Lignite Establishment was founded to feed

the biggest coal power station with a capacity of 20 mtpy. As the largest open cast mining project in the country, 6 bucket wheel excavators, 5 spreaders, 5 reclaimers and a belt conveyor system of approximately 55 km in total length are utilised. There is a lignite fired Thermal Power Plant, with an installed capacity of 4x340 MWe. The construction of a thermal power plant Elbistan B (with an installed capacity of 4X300 MWe) has been started Elbistan.

Kangal Deposit

The Pliocene deposit is situated at 25 km south of Kangal city in the east of central Turkey (Fig.1). Stratigraphically these sectors are very similar. The basement is made up of the Mesozoic semi-metamorphic limestones and ophiolites. Neogene sediments lie unconformably over the basement. These are divided into two formations. The Kalburçayırı Formation begins with gravels at the base, and is overlain by coaly units. There are gastropod fossils within the coal and coaly clays. Bicir Formation lies concordantly over the Kalburçayırı Formation. Bicir Formation is easily distinquishable by its yellowish white coloured limestones, clayey limestones and marls. Post Neogene rocks are volcanic and the Quaternary is made up of terrace gravels and slope debris. There are two coal seams, the bottom and upper. The average thickness of bottom seam varies between 8 and 15 m and the average thickness of upper seam varies between 2 and 12 m. The percentages of average moisture, ash, and total sulphur in the original coal are; 49-52%, 19-21%, and 2.02-3.57 %, respectively and the calorific value varies from 1207-1494 $kcalkg^{-1}$ (Tab.1). The total reserves are 202 607 000 tonnes. There is a lignite fired Thermal Power Plant, with an installed capacity of 2x150 MWe. At present, an additional unit of 1x150 MWe capacity is being built.

Çan Deposit

These Miocene coals are found in and around Çan within the county of Çanakkale in northwest Turkey (Fig.1). The basement is made up of the Palaeozoic phyllites, the Mesozoic arkoses, limestones, spilite and diapsidic diabases. The Miocene is represented by the lignitic clays and tuffite layers reaching up to 400 m in thickness above the basement. The Pliocene is made up of agglomerates about 300 m in thickness. The Plio-Pleistocene is made up of young andesitic volcanic rocks. The Quaternary is in the form of gravel terraces and alluvium. There is only one seam with an average mineable thickness of 16 m. The percentages of water, ash and total sulphur in the original coal are 18%, 28% and 4.20 % respectively, having a calorific value 2994 $kcalkg^{-1}$. The total reserve is 86 887 000 tonnes (Tab.1). The construction of the first fluid-bed thermal power plant has begun in Çan.

General Economic Evaluations and Results

From the studies up to now the total lignite reserves in Turkey have been estimated to be about 8,4 Gt; 3,9 Gt of which are the exploitable reserves. The lignite reserves of Turkey are around 2 % of the world total [3].

Almost 80 % of the total reserves are with calorific values below 2500 $kcalkg^{-1}$, 13% are in between 2500-3000 $kcalkg^{-1}$, while only the 7 % are over 3000 $kcalkg^{-1}$. Calorific value for industry and household must be greater than 3000 $kcalkg^{-1}$. It can be

seen that 93 % of total reserves can not be used for industry and household purposes. These low calorific value lignites can only be used for power plants. Production of electrical energy in Turkey is carried out in thermal and hydroelectric power plants. The total installed capacity is 20125 MW. The proportion of thermal power plants in the total installed capacity is about 52 % (10443 MW), the rest belongs to hydro electrical plants. The installed capacity of the lignite fired power plants is 5450 MWe. These are Afşin-Elbistan, Çayırhan, Kangal, Orhaneli, Seyitömer, Soma, Tunçbilek, Yatağan, Yeniköy and Kemerköy.

Lignite is used mainly to generate electricity in thermal power stations (67.4 %), for domestic heating (16.5 %), industrial factories (15.7 %), and internal consumption (0.4 %) [1]. The lignites having low calorific values are generally consumed for power plants under the state ownership. Private lignite companies usually supply lignite for domestic and industrial uses.

Taking into consideration the fact that the lignites used as fuel in power plants in Turkey have low calorific values and high sulphur and ash contents, the following measures are being implemented as much as possible to provide the country's energy need from national reserves, thus reducing the dependence on foreign sources in the energy sector, and also to minimize the impact on the environment of thermal power plants consuming large amounts of lignite :

- To prevent scenic pollution, concealment of the coal storing areas of the power plants (such as in Kemerköy Power Plant) in such a way as not to affect the natural environment and scenery;
- Provision of basement and border isolations of ash dump sites so as to provide the formation of infiltration of harmful liquids;
- Hydro transportation and storing of ash and other solid refuse in such a way as to prevent the environmental diffussion of such matter ;
- Trapping of airborne ash from chimneys with electrofilters with 99% effectivness (which are employed in every lignite power plants in Turkey);
- The construction of chimney desulphurization units to absorb harmful SO_X gases from plant chimneys (which are present in Çayırhan and Orhaneli Power Plants and the construction of which still continues Yatağan, Yeniköy and Kemerköy Power Plants);
- The use of the fluid-bed method, a modern incineration technology in the construction of new power plants that are to utilise lignites of high sulphur contents the power plant under construction in Çan is to employ this technology);
- Forestration of ash dumpsites and gradual substitution in the area of local flora sensitive to chimney gas emmisions with less sensitive ones (as is being done in the Yatağan Power plant region);

These are examples of environmental friendly use of coal in Turkey.

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