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ASSESSMENT OF TURKEY GEOTHERMAL RESOURCES

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ABSTRACT

Nearly 276 geothermal occurrences and fields are known to exist in Turkey according to MTA (the state owned directorate) records. Istanbul Technical University is conducting a study on assessment of the geothermal resources of Turkey to estimate the magnitude of geothermal resources and geothermal power production potential.

As a first step, the geothermal inventory data given by MTA, and also the data available for the fields given in the literature and as well as studied by our department in various projects are used to calculate the estimated apparent (identified) capacity. The apparent capacity was determined based on measured flow rate and temperature data of the produced fluids. Total geothermal apparent capacity was about 3700 MW_t (based on a reference temperature of 20 ^oC). Details about this study were presented by Satman et al.(2007).

As a second step, producible electric power based on volumetric reserve estimations of 11 relatively high temperature geothermal fields were predicted by evaluating existing geological, geochemical and geophysical data. According to Monte Carlo Simulation results, these eleven fields have 453 MW_e of power generation potential and 13 876 MW_t of geothermal energy potential for P10. The methodology and details were presented by Serpen et al.(2008).

As a third step, the producible thermal power values of the 19 relatively medium temperature geothermal fields available for direct utilization were estimated and the results obtained are presented in this paper. Results are discussed in terms of apparent capacity, simulation results and recoverable heat resource base.

Moreover, additional work is conducted to obtain the subsurface geothermal temperature distribution of Turkey. On the basis of preliminary information, computed temperature distribution map at 500 m depth is given in this study. Finally, the results of a study on heat content based on measured temperature gradient data throughout Turkey are presented.

INTRODUCTION

The energy and electricity demands in Turkey grow at about 4.5% and 7.5% per year, respectively. This is mainly due to increasing Turkey's population along with industrialization and electrification of our society. Turkey's energy consumption and electricity generating installed capacity have reached to 106 million TOE (tonnes oil equivalent) and 41 000 MW_e, respectively. Most of this increase resulted from adding more fossil fuels (mainly oil and natural gas) into the energy sector. However these fossil fuels are imported and therefore energy dependency on imported resources has become an important issue and of concern.

Geothermal energy, as a renewable resource, provides an opportunity for capacity expansions of domestic energy potential. Our national energy policy has recently considered the geothermal resources for expanding our energy supply portfolio and efforts to benefit more from them by privatizing the available and known geothermal fields and encouraging the installation of power generating plant are underway. New geothermal legislation calls for license applications and license applications announced in 2008 and planned for 2009 are expected to attract considerable investments in geothermal projects in coming years in Turkey.

Turkey's vast geothermal resources fall into two broad categories: hydrothermal and hot rock resources (EGS). All current geothermal exploration and development projects in Turkey are focused on hydrothermal.

To evaluate the potential of geothermal energy for Turkey, an assessment study has been underway by Istanbul Technical University. Study investigates the geothermal resources including the currently economic hydrothermal resources as well as the thermal energy (heat content) stored in the Earth.

Conventional hydrothermal resources are used for both electric and non-electric applications in Turkey and the number of applications increases by time. Beyond these hydrothermal resources are Engineered (or Enhanced) Geothermal Systems (EGS) resources with potential for heat recovery using present and future technologies. Implementations of EGS resources exist at a number of sites around the world and the EGS resources are believed to have a large potential for the long term. We focused our efforts on evaluating the recovery potential of hydrothermal and EGS resources.

The first phase of our study considered the geothermal resource in detail and collected the field and well data available. The data relevant to all manifestations and fields were analyzed to estimate an apparent capacity (Satman et al., 2007). In the second phase we used Monte Carlo type probabilistic reserve (or potential) estimation methods to estimate heat recovery from individual high and medium enthalpy fields in terms of MW_t and MW_e (Serpen et al., 2008; Korkmaz Basel et al., 2008 a).

The third phase of our study concerns on estimating the geothermal resource down to the depth of 3 km from the surface. The temperature measurements from the deep wells at least with a depth of 1 km as well as the results of temperature estimates from the geochemical studies for shallower wells were reviewed. As a result of this phase estimates for the geothermal resource and hydrothermal potentials have been obtained using some reasonable assumptions. We are aware of the risks and uncertainties involved in those estimates. The main constraint is related to the limited number of measurements of our database. Using the geothermal resource we have reached some range of estimates of the hydrothermal resource and estimates of the extractable portion of heat. Our ongoing efforts to improve the database and methods for estimates are continuing. Another aim of the third phase of our study is to develop a subsurface temperature distribution map.

Parts of results obtained from our study are presented and discussed in this paper.

RESULTS AND DISCUSSIONS

The Subsurface Temperature Map

Figure 1 shows the temperatures at depth of 500 m where one can easily sees that the western region of the country has higher temperature than the other regions (Korkmaz Basel, Cakin, Satman, 2008 b). This fact leads to substantial regional differences in rock temperature.

Two data sets were used to produce the map given in Fig. 1: 1) data used to produce the temperature gradient map published by Mihcakan et al. (2006) (see Figure 2), and 2) data used to develop the heat flow map of Turkey, given by (Ilkisik, 2008).

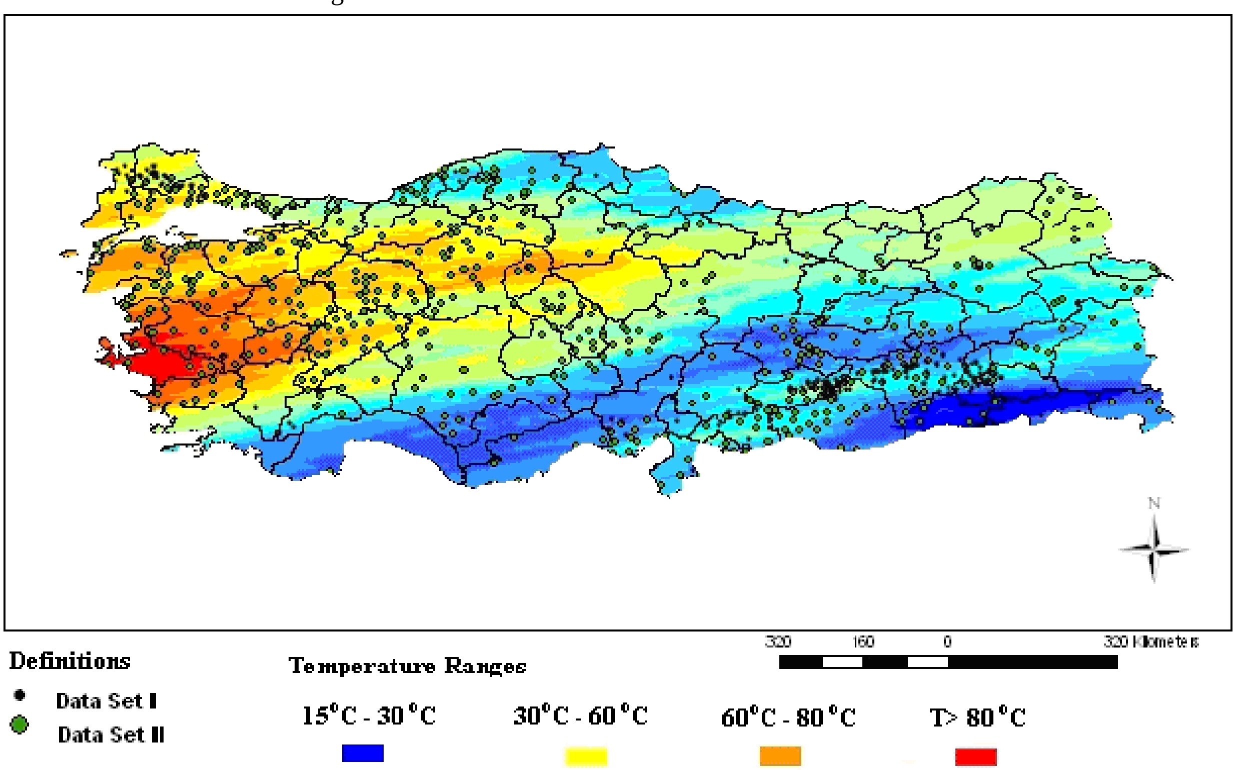

Figure 1: The map of temperature distribution at 500 m (Korkmaz Basel et al., 2008 b).

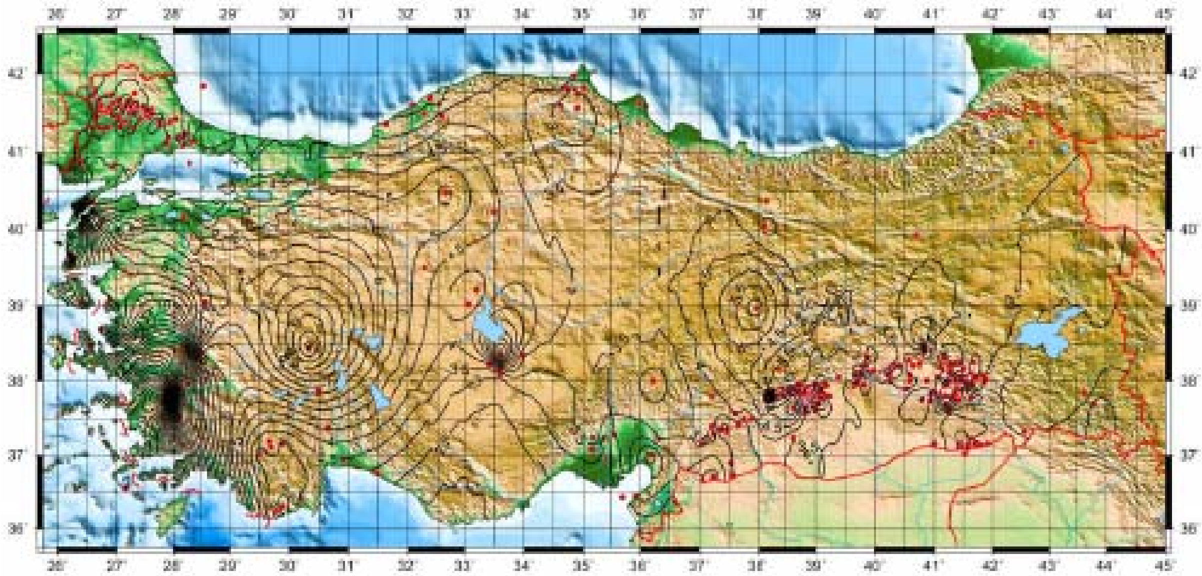

Figure 2: Temperature gradient map (Mihcakan et al., 2006).

Table 1. Stored thermal energy for Turkey.

Stored Thermal Energy					
Temperature, ^{o}C	**Class I (T<100 ^{o}C)**	**Class II (100 ^{o}C <T<150^{o}C)**	**Class III (150 ^{o}C <T<250^{o}C)**	**Class IV (T>250^{o}C)**	**Total (Joule)**
EPRI, 1978	1.9x10^{23}	8.4x10^{22}	2.3x10^{22}	1.4x10^{21}	**3.1x10^{23}**
Serpen, 1996	1.6x10^{23}	9.3x10^{22}	3.2x10^{22}	---	**2.9x10^{23}**
Serpen & Mıhçakan, 1996	7.1x10^{22}	**(100 ^{o}C <T<180^{o}C)**	**(180 ^{o}C <T<250^{o}C)**	---	**2.0x10^{23}**
		1.1x10^{23}	1.5x10^{22}		
Satman, 2007	1.8x10^{23}	1.2x10^{23}	6.3x10^{22}	6.9x10^{20}	**3.7x10^{23}**
This Study	1.72x10^{23}	1.3x10^{23}	6.4x10^{22}	3.02x10^{22}	**3.96x10^{23}**
Stored Thermal Energy Range: 2.0x10^{23} J – 3.96x10^{23} J					

241 data points obtained from the wells with at least a depth of 1 km from Mihcakan et al. (2006)'s study and 543 data points obtained from chemical analysis of relatively shallow wells from İlkisik's data were used to draw Figure 1.

Notice that the map is based on available data and it is likely additional areas of relatively high temperatures will be identified in areas not yet depicted.

Stored Thermal Energy

Using the temperature versus depth information obtained from the temperature gradient map given by Mihcakan et al. (2006), the amount of stored thermal energy for a given location could easily be determined. Table 1 shows the amount of energy as a function of temperature class at depth to 3 km for Turkey. For the purpose of this study, the geothermal resource base is defined as the total heat contained in subsurface rocks and fluids to a depth of 3 km and temperatures above 15 ^{o}C. Four temperature resource classes are considered:

Class 1: T< 100 ^{o}C
Class 2: 100<T<150 ^{o}C
Class 3: 150<T<250 ^{o}C
Class 4: T>250 ^{o}C

Although the heat capacity of rock depends on lithology, porosity, and water content, an average specific heat (C_v) of 2.55 J/(cm^{3}.^{o}C) (or 1000 J/(kg.^{o}C)) is an acceptable value for most areas.

The resource base, Q, associated with a particular temperature class is given by

$$Q = AHC_v(T-15) \text{ or } Q = \rho C_p V(T-15) \qquad (1)$$

where A denotes the area underlain by the resource, H the thickness (depth range) of the resource, C_v the volumetric heat of the subsurface material, ρ the density of the rock, T the average temperature of the resource.

Results obtained from various studies given in Table 1 indicates that the total geothermal resource base for Turkey is estimated to be an average value of $3x10^{23}$ J with a deviation of $\pm 1x10^{23}$ J.

Producible Thermal Power Study

Probabilistic methods were employed to provide an approach that accounts for both the uncertainty in each of parameters that affect reserves of individual development and production. The stored heat method is well suited to being adapted to a probabilistic approach. We used the "Monte Carlo Simulation" technique to allow the variables to vary over a defined range, with the probability of any particular value being determined from an appropriately defined distribution. Using this technique, a random number is first generated and then used with the defined probability distribution to determine the values of the variables. The stored heat is then calculated using the generated values. This process is repeated until a well defined probability distribution for heat output (MW_t or MW_e) can be generated. The triangular and uniform distribution can be used to describe each of the variables. The results from a Monte Carlo Simulation are presented as a histogram of number of occurrences of a particular value and as a plot of the Cumulative Distribution Function (CDF). The CDF plot shows the probability of MW_t or MW_e. The median value occurs at a cumulative probability of 0.5 (P50). Terms such as "P10", "P50" or "P90" are used for the value at the 10^{th}, 50^{th} or 90^{th} percentile.

We initially used Monte Carlo type probabilistic reserve (or potential) estimation methods to estimate heat recovery from individual high enthalpy fields in terms of MW_t and MW_e (Serpen et al., 2008). We studied a total of eleven fields. The industrial lifetime and abandonment temperature were assumed to be 30 years and 100 ^oC, respectively. Our recent studies with updated data indicated that the MW_e values for P10, P50 and P90 were determined to be 453, 737 and 1147, respectively. For a reference temperature of 15 ^oC, the thermal energy power (MW_t) values for P10, P50 and P90 were also estimated to be 13 876, 22 331 and 34 199.
The Monte Carlo Simulation approach was also utilized to estimate the geothermal energy potential for 19 middle and low enthalpy geothermal fields in Turkey (Korkmaz Basel et al., 2008 a). An industrial lifetime of 30 years and reference (abandonment) temperature of 15 ^oC were assumed for the evaluation process. The results are summarized in Table 2 and Figure 3 as P10, P50 and P90 values of geothermal potentials for individual fields' district heating. As can be seen from Table 2 and Figure 3 nineteen fields have 1573, 2587 and 4027 MW_t values for P10, P50 and P90, respectively.

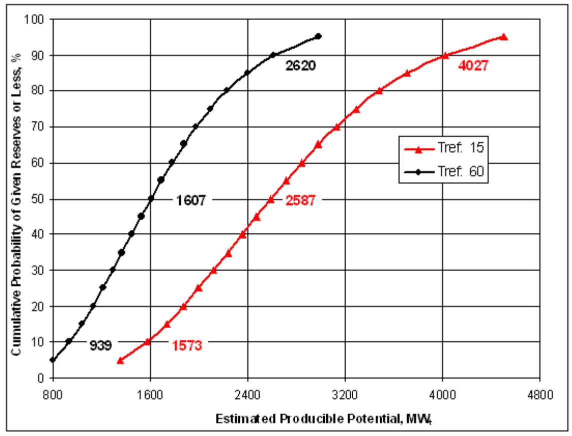

Figure 3: Monte Carlo Simulation results for district heating fields.

For the 27 fields studied so far, the combined thermal energy power (MW_t) values for P10, P50 and P90 are 14 387, 23 212 and 35 634 for a reference temperature of 15 ^oC, respectively.

Satman et al. (2007) presented results related to the identified geothermal capacity of all geothermal occurrences discovered in Turkey considering the flow rate and temperature data of the produced fluids. They concluded that the identified geothermal energy capacity was 3700 MW_t based on a reference temperature of 20 ^oC or about 3850 MW_t on a reference temperature of 15 ^oC. Results obtained from the Monte Carlo Simulation as discussed above differ from Satman et al.'s results, because Satman et al.'s results reflect the identified capacities whereas the Monte Carlo Simulation results reflect the potentials.

The identified thermal capacity fractions of the heat recovery results obtained from Monte Carlo Simulation approach represent the identified part of the total hydrothermal heat recovery potential and they are presently determined to be 27%, 17% and 11% for the P10, P50 and P90 values, respectively.

According to Stefansson (2005) theoretical considerations based on the conditions in Iceland and USA reveal that the magnitude of hidden (unidentified, geothermal resources without surface manifestations) is expected to be 5-10 times larger than the estimate of identified resources. In general, it is assumed that the number of undiscovered hidden resources is larger than the number of identified resources. Undiscovered resources are not mentioned explicitly in the assessment of identified capacities for Turkey (3700 MW_t), but their size is implicit in the geothermal resource (see Table 1).

Table 2. District heating potentials of 19 fields.

Fields	District Heating Potentails, MW_t (T_{ref}: 15°C)				District Heating Potentails, MW_t (T_{ref}: 60°C)			
	Probability			Cumulative%	Probability			Cumulative %
	10%	50%	90%		10%	50%	90%	
1. Simav	671	1055	1578	41	514	823	1231	51
2. Dikili	353	576	869	22	222	379	620	24
3. Ömer-Gecek	157	235	312	9	58	92	142	6
4. Sandıklı	53	98	170	4	17	36	72	2
5. Diyadin	50	96	174	4	17	37	73	2
6. Balçova	38	75	145	3	23	45	87	3
7. Kozaklı	40	71	120	3	24	45	81	3
8. Bergama	31	58	104	2	5	14	34	1
9. Kızılcahamam	28	50	85	2	11	23	45	1
10. Gönen	26	46	80	2	9	23	48	1
11. Sorgun	23	39	62	2	10	20	35	1
12. Salihli	20	34	55	1	8	15	24	1
13. Armutlu	19	32	54	1	6	13	29	1
14. Kuzuluk	17	31	53	1	9	17	31	1
15. Güre	14	27	49	1	0	4	15	0
16. Edremit	14	23	36	1	4	9	18	1
17. Yerkoy	8	14	23	1	0	5	11	0
18. Hisarköy	5	16	39	1	2	6	18	0
19. Kırsehir	6	11	19	0	0	1	6	0
Total	**1573**	**2587**	**4027**	100	**939**	**1607**	**2620**	100

Assuming that unidentified resources as 5-10 times larger than the identified resources, Satman (2007) points out the total (identified + unidentified) hydrothermal resource potential of Turkey is 19 000-37 000 MW_t.

Estimating the hydrothermal fraction of any underground geothermal resource is inherently speculative. In addition to estimating the hydrothermal fraction of the geothermal resource, it is important to also estimate the amount of recoverable fractions of hydrothermal and total geothermal resource.

For the recoverable fraction of stored thermal energy, MIT (2006) suggests 2%-20% range for EGS systems whereas Sanyal et al. (2004) suggests 0.03 to 0.17 range with a mean value of 0.11 for the US hydrothermal systems. MIT report gives the estimates for recoverable energy for USA assuming that EGS projects have a project life of 30 years and the abandonment temperature had a value of 10 °C below the initial rock temperature. Estimating the hydrothermal fraction of the geothermal resource and the amount of recoverable fractions of hydrothermal and total geothermal resource is subject to our ongoing and future studies.

CONCLUSIONS

Istanbul Technical University is conducting a study on assessment of the moderate- and high-temperature geothermal resources of Turkey. The aim of our study is to present estimates of geothermal resources and geothermal energy production.

The following results have been obtained in this study:
1) An estimate of Turkey geothermal resource potential of rocks shallower than 3 km is presented in this paper. It is found that the most likely value for this potential is $3 \pm 1 \times 10^{23}$ J.
2) Assessment based on Monte Carlo Simulation study indicates that for the 27 fields studied so far, the combined thermal energy (MW_t) values for P10, P50 and P90 are 14 387, 23 212 and 35 634 for a reference temperature of 15 °C, respectively.
3) The temperature distribution map at 500 m is built.
4) The total geothermal capacity of identified fields is 3850 MW_t based on a reference temperature of 15 °C.

We are aware of the risks and uncertainties involved in those estimates. The main constraint is related to the limited number of measurements of our database. Using the geothermal resource we have reached some range of estimates of the hydrothermal resource and estimates of the extractable portion of heat. Our ongoing efforts to improve the database and methods for estimates are continuing. With addition of new, revised and updated data better and more accurate estimates of the geothermal capacity and potential will be possible.

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