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Turkey Geothermal Resource Assessment

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ABSTRACT

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. The geothermal potential and dependency on imported energy sources are stimulating geothermal energy exploration and development projects in Turkey.

To evaluate the potential of geothermal energy for Turkey, an assessment study has been underway by Istanbul Technical University. Our ongoing study focuses on estimating the potential of geothermal fields in terms of electricity generation and non-electric thermal production. We focus our efforts on two resource categories: (1) hydrothermal resources shallower than 3 km, and (2) geothermal potential of Turkey obtained using terrestrial heat flow. Our results so far reveal that the geothermal resource potential of rocks shallower than 3 km is $3 \pm 1 \times 10^{23}$ J. Taking the results of the Monte Carlo Simulation studies for medium-to-high temperature geothermal (hydrothermal) fields (a total of 40 individual fields) as an estimate of the lower limit of the geothermal potential, the lower limit of Turkey geothermal potential for electricity generation is estimated to be 661 MW_e and the corresponding value for direct use to be 18077 MW_t, both values valid for P10 (Cumulative Probability of 0.1) for a reference temperature of 100 ^oC and 15 ^oC.

As of May 2009, the identified geothermal capacity of all geothermal occurrences discovered in Turkey has reached about 4800 MW_t on a reference temperature of 15^oC. The installed capacity is estimated about 80 MW_e for electricity generation whereas the energy use is estimated to be 800 MW_t for direct use and nearly 50 MW_e for electricity generation. However, the ongoing field development projects, particularly for the electricity generation, are expected to increase those figures respectively in near future.

This paper describes the methodology and presents the updated results in terms of identified hydrothermal capacity, geothermal resource base, and EGS potential. Furthermore, the subsurface temperature distribution map at 500 m depth is discussed.

1. INTRODUCTION

As a developing country Turkey is growing rapidly each year. But its existing energy production almost depends on non renewable resources/fossil fuels. Nearly 75% of energy demand is satisfied with the imported fuels. And the percentage of the imported energy is increasing each year due to progress and development of the country. Turkey's energy consumption and installed power generation capacity have reached to 106 million TOE (tones oil equivalent) and 42 GW_e, respectively. In order to reduce energy dependency the country needs energy diversification. This diversification could be obtained by adding renewable resources (wind, geothermal, solar) to energy supply portfolio.

All along it is said that Turkey is rich in renewable energy resources potential like wind, geothermal and solar. But these resources are not yet evaluated enough in terms of energy production. Although it will give a modest contribution, Turkey needs to include the geothermal resources to its energy supply portfolio. The determination of this contribution in a scientific manner is the aim of this study.

Geothermal exploration started in the beginning of 1960s in Turkey. Firstly in 1968, a high enthalpy geothermal field Kızıldere, was discovered. Two medium temperature geothermal fields Balçova and Seferihisar were found and studied in 1960 and 1970s respectively. A second high enthalpy system Germencik and various other medium enthalpy fields such as Salavatlı and Simav were identified in the 1980s. Although geothermal activities have been continuing more than 45 years in Turkey, low and medium temperature resources have not yet explored and evaluated in details.

2. TURKEY'S GEOTHERMAL RESOURCE POTENTIAL

Turkey is very active with tectonically and also experienced volcanic activities. Turkey's vast geothermal resources fall into two broad categories: hydrothermal (from relatively hot ground water) and hot rock resources (EGS). All current geothermal exploration and development projects in Turkey are focused on hydrothermal. For the purpose of this study, geothermal resource base is defined as, the total heat contained in subsurface rocks and fluids between the surface and down to a depth of 3 km and temperatures above 15^oC. First study was reported about the geothermal resource potential in 1978 by EPRI (Energy Production Research Institute). Afterwards, by the following years, some other various studies were done by the researchers. And finally Basel at al. (2008b), made a study on the thermal energy (heat content) stored beneath Turkey. All potential figures obtained for Turkey is given in Table 1. Basel at al.,(2008b) used the temperature versus depth information obtained from the temperature gradient map given by Mihcakan et al. (2006), the estimated gradient values are extrapolated to 3 km depth and determined the amount of stored thermal energy for a given location considering the four temperature resource classes.

Temperature classes are as follows; Class 1: T< 100 ^oC, Class 2: 100<T<150 ^oC, Class 3: 150<T<250 ^oC and Class 4: T>250 ^oC.

Table 1: Turkey's geothermal resource base (in 10^{23} J) at 3 km depth for different temperature classes (Basel et al., 2008b).

Reference	Temperature, °C				
	Class I	**Class II**	**Class III**	**Class IV**	**Total.**
EPRI- 1978	1.9	0.84	0.23	0.14	3.1
Serpen-1996	1.6	0.93	0.32	-	2.9
Serpen Mihcakan-1996	0.71 T<100	1.1 100<T<180	0.15 180<T<250	-	2.0
Satman-2007	1.8	1.2	0.63	0.007	3.7
Basel at al.-2008	1.72	1.3	0.64	0.3	3.96

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

$$Q = AHC_v(T - 15) \tag{1}$$

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, T the average temperature of the resource. 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. Here, 15 is taken as the mean annual atmospheric temperature for Turkey.

Results obtained in Table 1 indicate 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. The difference between the results is mainly due to chosen data (maps) and mean annual atmospheric temperature. For example while Serpen and Mihcakan (1999)'s study based on heat flow maps, Basel at al., (2008b)'s study based on gradient data obtained from the petroleum and natural gas wells at least with 1 km depth.

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 in the long term. Our efforts are focused on evaluating the recovery potential of hydrothermal and EGS resources.

The stored heat of Turkey between the depths of 3 to 10 km is estimated. The obtained result for each depth and depth interval considering the temperature classes is given in Table 2 and Table 3 respectively.

3. PRODUCIBLE THERMAL POWER

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 10th, 50th or 90th percentile.

Table 2: Turkey's stored heat at 1 km depth intervals.

Depth Interval, km	Stored Heat, x 10^{23}J
3-4	3.06
4-5	3.97
5-6	7.01
6-7	3.56
7-8	6.61
8-9	8.74
9-10	8.37

Table 3: Turkey's geothermal resource base (in 10^{23} J) between 3 to 10 km depth for different temperature classes.

	Temperature, °C				
	T<100	100<T<1500	150<T<250	T>250	Total.
3	1.72	1.3	6.39	3.02	3.96
4	1.77	2.31	1.78	1.17	7.03
5	1.77	2.61	4.20	2.41	11
6	1.77	2.70	6.54	6.99	18
7	1.77	2.70	7.93	9.16	21.6
8	1.77	2.70	8.54	1.52	28.2
9	1.77	4.15	8.66	2.23	36.9
10	1.77	4.15	8.81	3.05	45.3

We initially used Monte Carlo type probabilistic reserve (or potential) estimation methods to estimate heat recovery from eleven high enthalpy fields in terms of MW_t and MW_e (Serpen et al., 2008). After adding 4 other suitable fields for power generation, totally fifteen fields are currently investigated. The industrial lifetime and abandonment temperature were assumed to be 30 years and 100 ^{o}C, respectively. Our recent studies with updated data indicated that the MW_e values for P10, P50 and P90 were determined to be 661, 791 and 962, respectively. For a reference temperature of 15 ^{o}C, the thermal energy power (MW_t) values for P10, P50 and P90 were also estimated to be 18077, 21460 and 28390. Field's individual values for electric applications are given in Table 4 and the simulation results for 100 ^{o}C reference temperatures are shown in Figure 1.

Since there will be bidding for transferring the consents of some these fields from the state to the private sector in near future, some of the names of fields given in Table 4 have not been disclosed to avoid influencing the bidding process.

The Monte Carlo Simulation approach was also utilized to estimate the geothermal energy potential for 28 middle and low enthalpy geothermal fields in Turkey. An industrial lifetime of 30 years and reference (abandonment) temperature of 15 ^oC were assumed for the evaluation process. The results are summarized in Figure 2 and Table 5 as P10, P50 and P90 values of geothermal potentials for individual fields' district heating. As can be seen from Figure 2 and Table 5 twenty eight fields have 3365, 3895 and 4571 MW_t values for P10, P50 and P90, respectively.

Table 4: Power potentials of 15 major fields, MW_e (T_{ref}: 100^{o}C).

Fields	P10	P50	P90
1. Balçova	0.3	0.8	1.8
2. Zilan-Ercis	0.6	1.8	3.5
3. Tuzla	3.6	6.6	11.5
4. (S)	2.4	4.5	7.9
5. Dikili	5.3	11.5	23.3
6. (T)	5.2	8.5	12.9
7. Seferihisar	5.3	14.5	26.3
8. (U)	10.4	13.1	16.7
9. Simav	21.9	35.6	54.5
10. Germencik	24.6	43	70.6
11. (X)	28.4	45.9	69.5
12. (Y)	50.5	83.9	134
13. Salavatlı	63	119	215
14. Kızıldere	88.2	112	140
15. (Z)	162	264	401

Table 5: District heating potentials of 28 fields, MW_t (T_{ref}: 15 ^{o}C).

Fields	P10	P50	P90
1. Simav, Kütahya	671	105	157
2. Dikili, Izmir	353	576	869
3. Şaphane, Kütahya	185	291	419
4. Ömer-Gecek, Afyon	157	235	312
5. Kestanbol, Çanakkale	140	295	576
6. Gediz, Kütahya	102	164	250
7. Karahayıt-Pamukkale, Denizli	69	125	216
8. Urganlı, Manisa	53	102	178
9. Sandıklı, Afyon	53	98	170
10. Diyadin, Ağrı	50	96	174
11. Gölemezli, Denizli	45	82	140
12. Kozaklı, Nevşehir	40	71	120
13. Balçova, Izmir	38	75	145
14. Bergama, Izmir	31	58	104
15. Kızılcahamam, Ankara	28	50	85
16. Gönen, Balıkesir	26	46	80
17. Yenice, Denizli	25	45	78
18. Sorgun, Yozgat	23	39	62
19. Salihli, Manisa	20	34	55
20. Armutlu, Yalova	19	32	54
21. Kuzuluk, Sakarya	17	31	53
22. Güre, Balıkesir	14	27	49
23. Edremit, Balıkesir	14	23	36
24. Heybeli, Afyon	13	28	54
25. Yerköy, Yozgat	8	14	23
26. Kırşehir	6	11	19
27. Hisarköy, Balıkesir	5	16	39
28. Demirci, Manisa	4	9	17

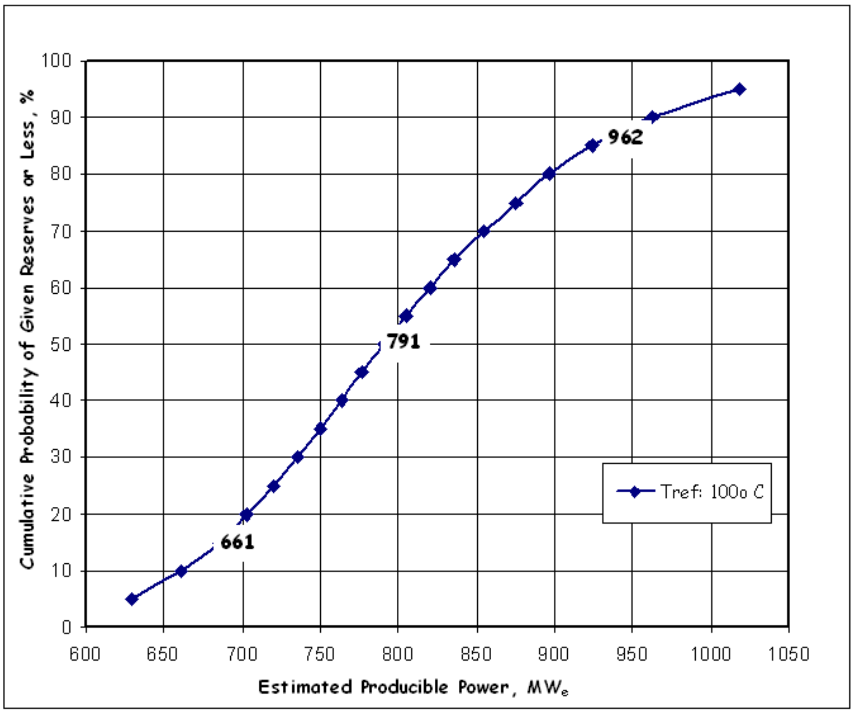

Figure 1: Monte Carlo Simulation results for power generation.

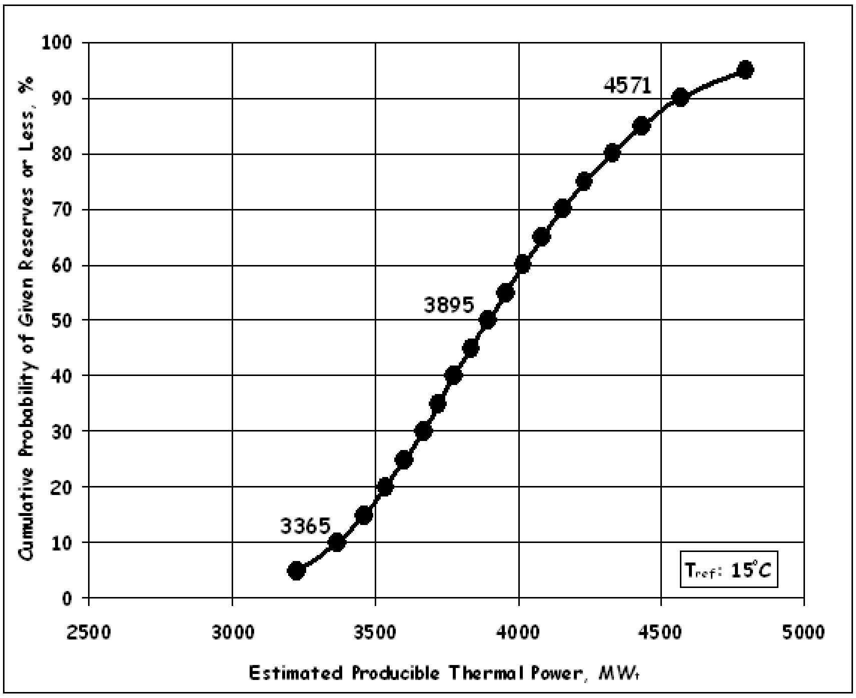

Figure 2: Monte Carlo Simulation results for district heating fields.

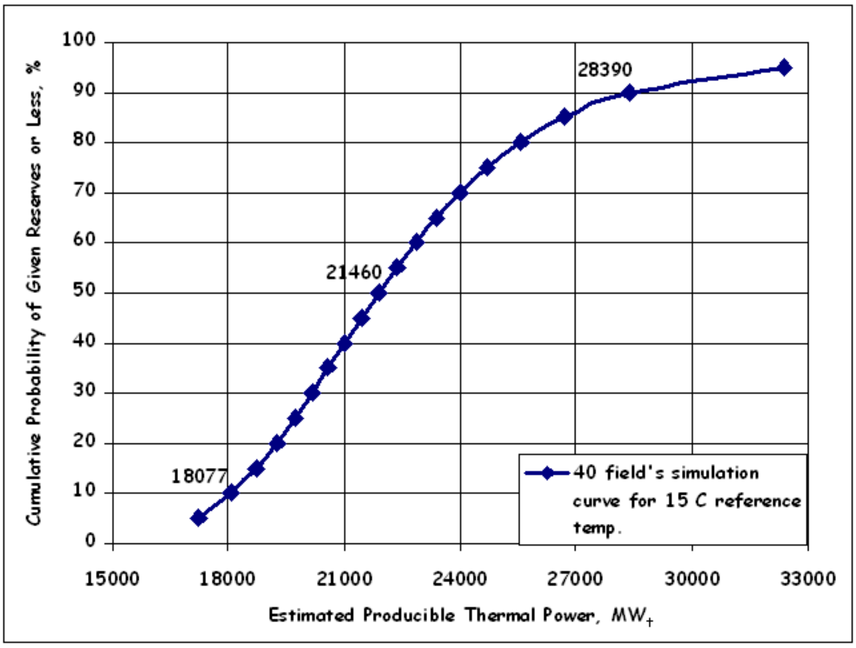

Figure 3: Monte Carlo Simulation results for investigated 40 fields.

For the 40 fields studied so far, the combined thermal energy power (MW_t) values for P10, P50 and P90 are 18077, 21460 and 28390 for a reference temperature of 15 ^oC, respectively (see Figure 3).

The frequency of both P10 value intervals (when the reference temperature is 15^{o}C) and the minimum temperature value intervals for 40 fields investigated are shown in Figure 4 and Figure 5 respectively.

4. IDENTIFIED (APPARENT) GEOTHERMAL CAPACIY

There are nearly 280 geothermal occurrences and fields known to exist in Turkey according to geothermal inventory data given by General Directorate of Mineral Research and Exploration (MTA, 1996 and 2005). In order to assess the identified geothermal capacity a detailed data inspection is conducted. Not only the data on wells drilled, flow rate and temperature measurements, water chemistry given by MTA (1996, 2005) but also the fields studied in literature and our department were all collected, analyzed and classified. All the collected data is used to estimate the geothermal potential of the country in terms of capacity. Here the capacity (apparent capacity/identified capacity), the thermal power in MW_t. is calculated in terms of the flow rates and the temperature values.

$$\text{Capacity} = w_{ave} \times 4.18 \times (T_{ave} - T_{ref}) \qquad (2)$$

where w_{ave}, T_{ave}, T_{ref} are average flow rate, average temperature and reference temperature respectively. Here although mean annual temperature changes from region to region, for Turkey this number could be taken as 15 or 20°C. Heat capacity of water (4.18 kJ/kg-°C) is taken as a constant number.

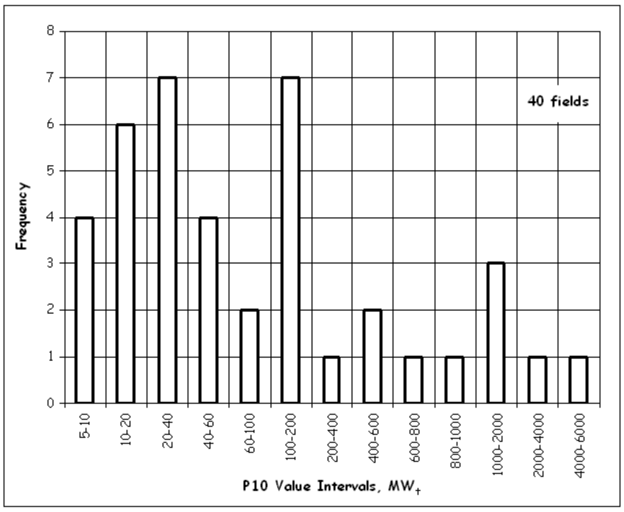

Figure 4: P10 value intervals Monte Carlo Simulation results for investigated 40 fields.

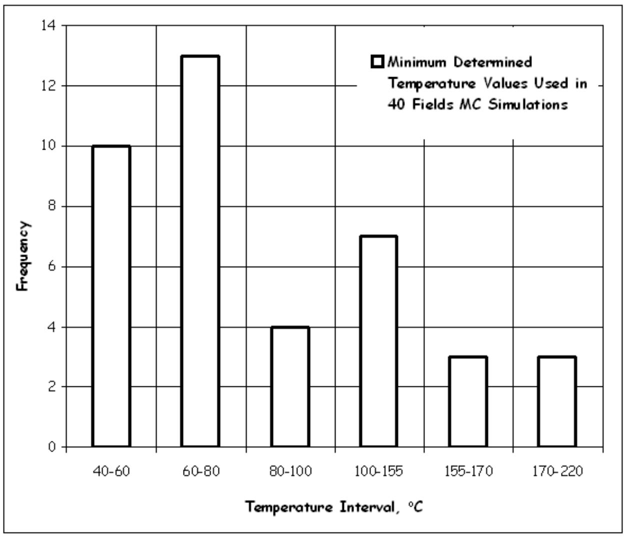

Figure 5: Temperature value intervals Monte Carlo Simulation results for investigated 40 fields.

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 °C or about 3850 MW_t on a reference temperature of 15 °C.

Our recent analysis indicate that as of May 2009 the apparent geothermal capacity based on nearly 280 localities with temperature higher than 20°C is 4500 MW_t and for 15°C is 4800 MW_t.

The major geothermal fields flow rates and temperature values are listed in Table 6.

Table 6: Major geothermal fields of Turkey.

Locality	Flow Rate (l/s)	Ave. Tem. (°C)	Max Temp. (°C)
Germencik (Aydın)*	1515	220	232
Sultanhisar-Salavatlı (Aydın)	731	163	171
Imamkoy (Aydın)+	40	142	
Ömer-Gecek (Afyon)+	817.5	94	
Kızıldere (Denizli)	250	217	242
Simav (Kütahya)	476	184	
Balçova (İzmir)	536	81	
Seferihisar (İzmir)	264	144	153
Diyadin (Ağrı)+	561	72	
Sandıklı (Afyon)+	496	68	
Dikili (İzmir)	250	120	
Terme (Kırşehir)	688	102	
Kozaklı (Nevşehir)+	247	91	
Gölemezli (Denizli)+	340	70	
Kuzuluk (Sakarya)+	271	81	
Tuzla (Çanakkale)+	120	160	174
Kula (Manisa)+	140	135	
Salihli (Manisa)	150	104	
Caferbeyli (Manisa)	6.5	155	
Kavaklıdere (Manisa)	6.5	215	

* MTA (1996), + MTA (2005)

According to our analysis, nearly 75% of these fields' apparent capacities are lower than 5 MW_t (Table 7).

Table 7: Apparent capacity frequencies of Turkey's geothermal occurrences (T_{ref}: 15°C totally 277 fields).

Apparent Capacity Interval, MW_t	Percentage of Geothermal Occurrence
0-5	74
5-10	7.9
10-20	4.3
20-30	4.3
30-40	1.4
40-50	1.1
50-60	0.7
60-80	1.8
80-100	0
100-200	2.9
200-300	0.7
300-400	0
400-500	0.4
500-1000	0
1000-2000	0.4

Figure 6 shows the apparent capacity frequencies of the 72 occurrences. The apparent capacity values of 205 occurrences lower than 5 MW_t, are not taken into consideration in Figure 6.

At present, the installed capacity of electricity power plants in Turkey is 80 MW_e. Table 8 shows existing and soon to be installed power plants in Turkey; four are in operation, and another two will be on line soon.

5. SUBSURFACE TEMPERATURE DISTRIBUTION MAP

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

Firstly 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 7.

In 2009, Turkey's temperature distribution map is revised with more and updated values. The new map is given in Figure 8. In the generation of this map, both set 1 (420 data points) and set 2 (555 data points) including totally 968 data points are used.

The new map is believed to depict the geothermal locations more in detail.

Table 8: Turkey's geothermal power generation.

Locality	Commissioned in (year)	Installed Capacity (MW_e)
Kızıldere (Denizli)	1984	17.8
Dora I Salavatlı (Aydın)	2006	7.35
Bereket Enerji (Denizli)	2007	7.5
Gürmat Germencik	2009	47.4
Tuzla (Çanakkale)	2009	7.5
Dora II Salavatlı (Aydın)	2010	9.7

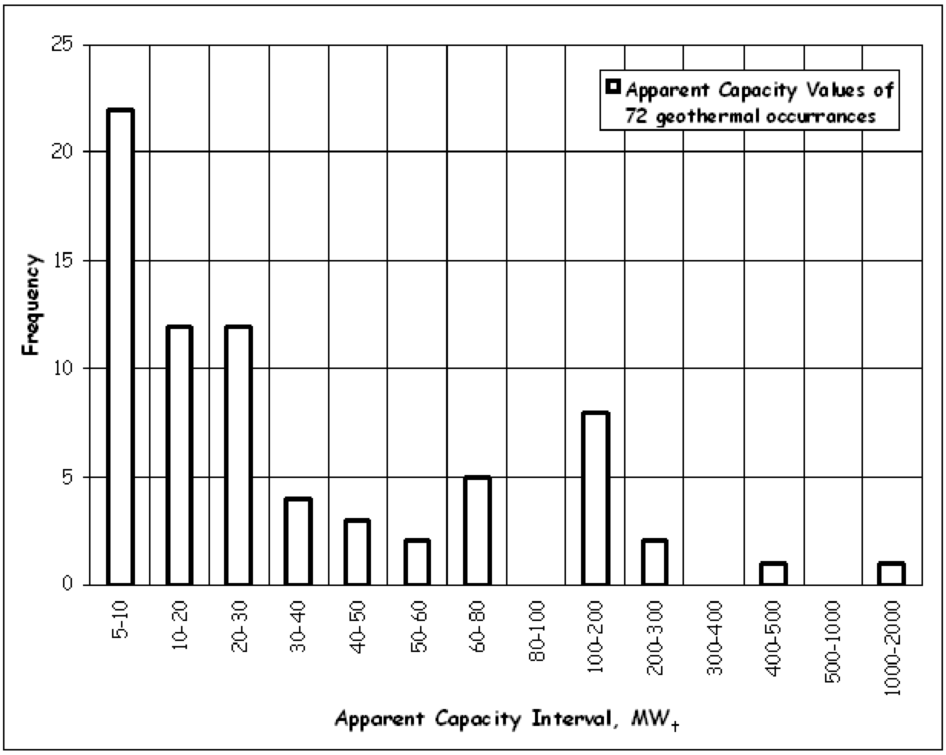

Figure 6: Frequency of apparent capacity values of 72 geothermal occurrences in Turkey.

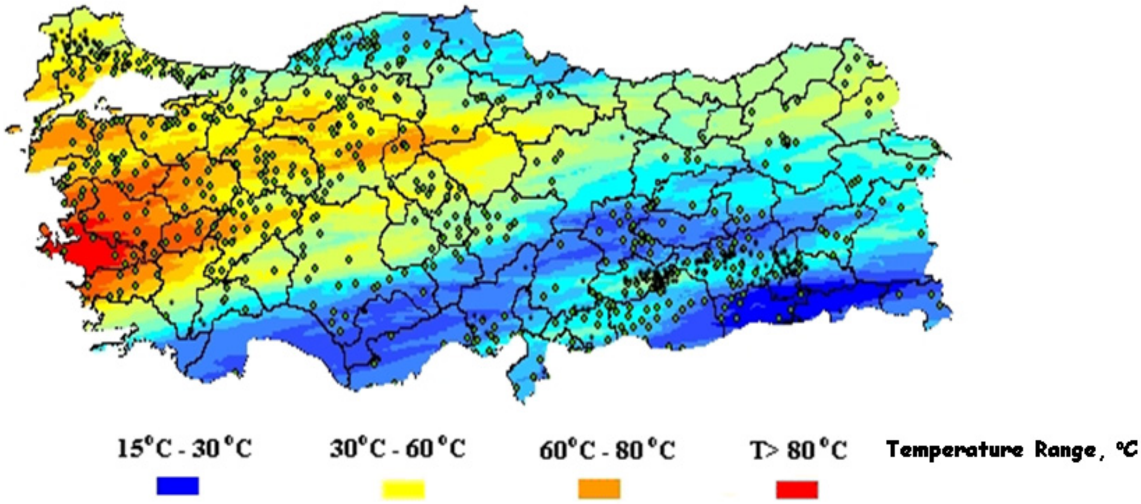

Figure 7: The map of temperature distribution of Turkey at 500 m (Basel et al., 2008b).

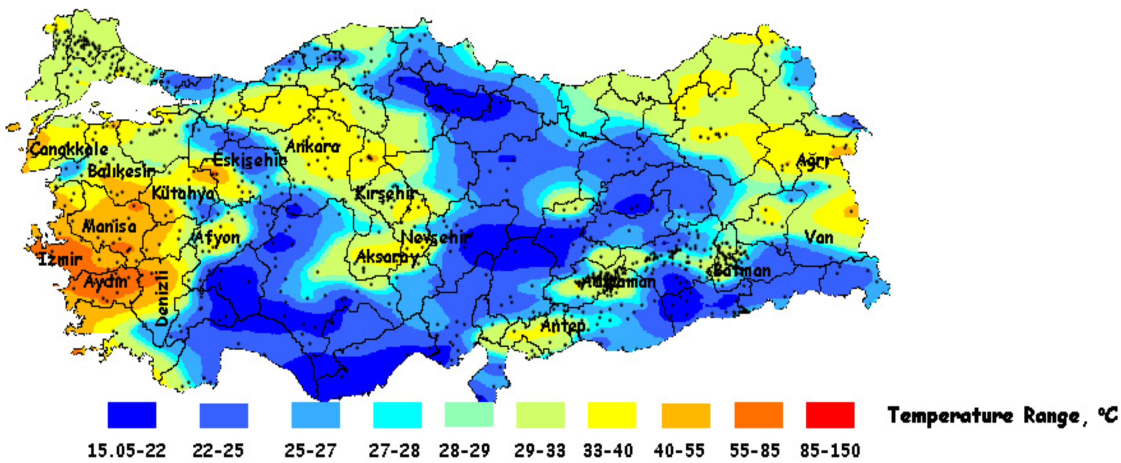

Figure 8: The map of temperature distribution of Turkey at 500 m.

6. 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 40 fields studied so far, the combined thermal energy (MW_t) values for P10, P50 and P90 are 18077, 21460 and 28390 for a reference temperature of 15 ^oC, respectively.

3) The temperature distribution map at 500 m is built.

4) The total geothermal capacity of identified fields is 4800 MW_t based on a reference temperature of 15 ^oC.

We are aware of the 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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