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TURKEY'S GEOTHERMAL ENERGY POTENTIAL: UPDATED RESULTS

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ABSTRACT

There are 276 geothermal occurrences including nearly 110 fields having at least one drilled well known to exist in Turkey with surface temperatures ranging from 22.5°C to 220°C according to both MTA 1996, MTA 2005 reports and private knowledge records. Most of these occurrences are mainly located along the major grabens at the Western Anatolia, the Northern Anatolian fault zone and Central and Eastern Anatolian volcanic regions. The surface temperatures in 80 of the occurrences are above 60°C, in 13 of them above 100°C and in 8 occurrences above 140°C. All the data given by MTA inventory and also the data available for the fields studied in the literature and as well as by our department in various projects are evaluated and used to estimate the identified apparent capacity. The identified apparent capacity is given in terms of maximum flow rate and the weighted flow rate temperatures. Total identified geothermal apparent capacity is about 4800 MW_t (based on a reference temperature of 15 °C) and 4500 MW_t (based on a reference temperature of 20 °C). According to our analysis, nearly 75% of these fields' current apparent capacities are lower than 5 MW_t.

A total of 55 potential geothermal fields are evaluated using volumetric reserve estimation method employing existing geological, geochemical and geophysical data. Seventeen geothermal fields with high temperatures (over 100°C) are suitable for electric power generation and the rest 38 are suitable for non-electric usages. According to Monte Carlo simulation results 17 fields have 710 MW_e (cumulative probability; P10) power generation potential. Presently with the existing four power plants, Turkey's installed capacity of electricity power is 80 MW_e. This amount is expected to reach 100 MW_e by the end of 2010 with additional two power plants. The estimated recoverable thermal energy of the other 38 geothermal fields evaluated for direct utilization is 2988 MW_t for 15°C reference temperature. The estimated recoverable thermal power of the investigated 55 fields is 23566 MW_t for a reference temperature of 15 °C. The results of this study in terms of identified apparent capacity, power generation potential and thermal energy potential are discussed.

Also results on heat content based on measured temperature gradient data throughout Turkey are presented. Our results so far reveal that the geothermal resource potential of rocks shallower than 3 km is $3\pm1\times10^{23}$ J.

Moreover, subsurface temperature distribution maps constructed using geo-statistical methods are given for detecting hot areas of Turkey and local regions.

INTRODUCTION

The energy consumption and installed power generation capacity of Turkey have reached to 106 million TOE (tones oil equivalent) and 44 GW_e respectively. Although geothermal energy has very little contribution, it has to be included in country's energy portfolio as a domestic supply.

Turkey is tectonically a very active region. Similar to the Western Great Basin of the USA, the western part of Turkey is a region of abundant geothermal activity currently undergoing significant exploration and exploitation but with relatively little volcanism.

The installed geothermal power has reached from 17 MW_e in 2005 to 80 MW_e at the end of 2009.
Presently the installed capacity of electricity power plants is 80 MW_e and this amount is expected to reach about 100 MW_e in 2010.

Direct use of geothermal energy in Turkey is focused on district heating, greenhouse applications, and thermal tourism. The first heating system was established in Gonen in 1978. Currently there are nearly 20 heating systems with 395 MW_t thermal capacity installed in the country. The total thermal capacity of the balneological sites is estimated to be 220 MW_t (Serpen et al., 2009). There are 10 greenhouse regions mostly located in the western parts of the country, totally covering 13 ha area with 165 MW_t thermal capacity.

Istanbul Technical University has been conducting a study on assessment of Turkey's geothermal resources. The aim of our study is to present current and updated estimates of geothermal resources and geothermal energy production in the country. It is an ongoing study. The previous results have already been reported by Satman et al. (2007), Serpen et al. (2008) and Basel et al. (2009). The updated results obtained in last one year are discussed in the following sections.

STORED THERMAL ENERGY

Thermal energy stored beneath the country is estimated in two phases: In the first phase the corresponding depth is taken as 3 km to estimate the shallow resources. In the second phase the corresponding depths are taken from 3 km to 10 km.

Results obtained the first phase indicates that the total geothermal resource base (the geothermal resource potential of rocks shallower than 3 km containing and including hydrothermal resources) for Turkey is estimated to be an average value of $3x10^{23}$ J with a deviation of $\pm 1x10^{23}$ J (Basel et al., 2009). This value corresponds to 0.7% amount of the world (EPRI, 1978).

Our estimate is based on temperature gradient data obtained from the petroleum, natural gas, and geothermal wells with at least 1 km depth. A gradient map generated by Mihcakan et al. (2006) is used and gradient values are extrapolated linearly and a constant mean annual atmospheric temperature is taken to be 15^o C.

Engineered (or Enhanced) Geothermal Systems (EGS) between 3 and 10 km depths are considered to be 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 (MIT, 2006). Therefore we conducted the second phase of our study.

In the second phase, potential of Turkey is processed considering temperature classes and the estimated potentials between the depths of 3 to 10 km are shown in Table 1. Estimated potential is obtained to be $4.4 x10^{24}$ J using gradient values.

The stored heat in each depth interval between 3 km to 10 km is determined and the obtained results are shown in Table 2.

Table 1: Turkey's geothermal resource base (in 10^{23} J) between 3 to 10 km depth for different temperature classes.

Depth, km	Temperature, ^oC				Total
	T<100	100<T<150	150<T<250	T>250	
	Stored Heat, x 10^{23} J				
3	1.72	1.30	0.65	0.30	3.97
4	1.77	2.31	1.97	1.01	7.06
5	1.77	2.61	4.22	2.41	11.01
6	1.77	2.70	6.55	4.85	15.87
7	1.77	2.70	7.94	9.19	21.60
8	1.77	2.70	8.54	15.2	28.21
9	1.77	2.70	8.86	22.4	35.73
10	1.77	2.70	9.01	30.6	44.08

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

Depth Interval, km	Stored Heat, x 10^{23}J
3-4	3.08
4-5	3.96
5-6	4.84
6-7	5.73
7-8	6.61
8-9	7.49
9-10	8.37

APPARENT CAPACITY

There are 276 geothermal occurrences including 110 fields having at least one drilled well are known to exist in Turkey with temperatures ranging from 22.5^oC to 220^oC according to both MTA 1996, and MTA 2005 (the state owned directorate) and private knowledge records. Most of these occurrences are mainly located along the major grabens at the Western Anatolia, the Northern Anatolian fault zone and Central and Eastern Anatolian volcanic regions. The temperatures in 80 of the occurrences are above 60^oC, in 13 of them above 100^oC and in 8 occurrences above 140^oC. All the data given by MTA inventory and also the data available for the fields studied in the literature and as well as by our department in various projects are evaluated and used to estimate the identified apparent capacity. The identified apparent capacity is given in terms of maximum flow rate and the weighted flow rate temperatures. Satman et al. (2007) study reported a total identified geothermal apparent capacity to be 3850 MW_t based on a reference temperature of 15 ^oC. Due to new exploration and production activities in the last two years, new fields were discovered and additional production wells were drilled in the available fields. Thus the flow rate and temperature data have been revised and updated. Then, our estimate of total identified geothermal apparent capacity is determined to be about 4800 MW_t (based on a reference temperature of 15 ^oC) and 4500 MW_t (based on a reference temperature of 20 ^oC). The apparent capacity values for different reference temperatures (40 ^oC, 60 ^oC, 100 ^oC and 140 ^oC) are also calculated and the results are shown in Table 3. According to our analysis, nearly 75% of 276 occurrences' current apparent capacities are lower than 5 MW_t (Table 4).

Table 3: Calculated Turkey's apparent capacity values for different reference temperatures.

Referance Temperature	Apparent Capacity, MW_t
15	4800
20	4500
40	3141
60	3037
100	1212
140	664

The major geothermal fields' flow rates and average and maximum temperature values are listed in Table 5.

Table 4: Apparent capacity frequencies of Turkey's 276 geothermal occurrences (T_{ref}: 15^{o}C).

Apparent Capacity Interval, MW_t	Occurrance Percentage ,%
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 1 shows the apparent capacity frequencies of the 71 occurrences with apparent capacities higher than 5 MW_t. The apparent capacity values of 205 occurrences lower than 5 MW_t, are not taken into consideration in Figure 1.

Table 5: Major geothermal fields of Turkey.

Locality	Flow Rate (l/s)	Ave. Tem. (^{o}C)	Max Temp. (^{o}C)
Germencik/Aydin*	1515	220	232
Sultanhisar-Salavatli /Aydin^{o}	731	163	171
Imamkoy/Aydin^{+}	40	142	
Omer-Gecek /Afyon^{+}	817.5	94	
Kizildere/Denizli^{o}	250	217	242
Simav/Kutahya^{o}	476	184	
Balcova/Izmir^{o}	536	81	
Seferihisar/Izmir^{o}	264	144	153
Diyadin /Agri^{+}	561	72	
Sandikli/Afyon^{+}	496	68	
Dikili/Izmir^{o}	250	120	
Terme/Kirsehir^{o}	688	102	
Kozakli/Nevsehir^{+}	247	91	
Golemezli/Denizli^{+}	340	70	
Kuzuluk/Sakarya^{+}	271	81	
Tuzla/Canakkale^{+}	120	160	174
Kula/Manisa^{+}	140	135	
Salihli/Manisa^{o}	150	104	
Caferbeyli/Manisa^{o}	6.5	155	
Kavaklıdere/Manisa^{o}	6.5	215	

* MTA (1996), $^{+}$ MTA (2005), ^{o} Our Data

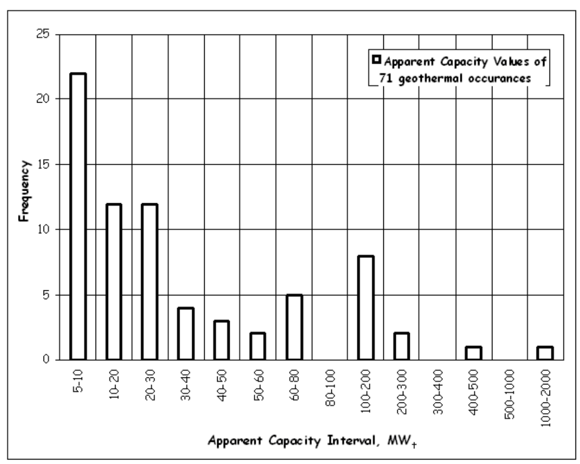

Figure 1: Frequency of apparent capacity values of 71 geothermal occurrences in Turkey.

RECOVERABLE THERMAL ENERGY POTENTIAL

The recoverable thermal energy is investigated in two categories: recoverable thermal energy for direct use and recoverable electric power generation.

We used Monte Carlo type probabilistic reserve (or potential) estimation methods to determine heat recovery from individual high and moderate temperature fields in terms of MW_t and MW_e.

Probabilistic methods are employed to provide an approach that accounts for the uncertainty in each of parameters that affect both reserves of individual development and recovery. 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 values at the 10^{th}, 50^{th} or 90^{th} percentile.

A total of 55 potential geothermal fields are evaluated using volumetric reserve estimation method employing existing geological, geochemical and geophysical data. 17 geothermal fields with high temperatures (over 100^oC) are suitable for electric power generation, and the rest 38 are suitable for non-electric usages. However, three geothermal fields could be classified both for direct and indirect uses. These three fields, namely Balcova/Izmir, Simav/Kutahya and Dikili/Izmir, due to their relatively low temperatures, could be exploited for both direct and indirect uses.

In the estimations for electric power generation the industrial lifetime and abandonment temperature were assumed to be 30 years and 100 ^oC, respectively. Power potentials of 17 major geothermal fields P10, P50 and P90 values are given individually in Table 6.

Since there will be bidding for transferring the consents of some of these fields from the state to the private sector in near future, the names of those fields given in Table 6 have not been disclosed to avoid influencing the bidding process. Those fields are represented by letters, P to Z in Table 6.

Table 6: Power potentials of 17 high temperature fields.

Fields	**P10**	**P50**	**P90**
1. Balcova/Izmir	0.3	0.8	1.8
2. Zilan-Ercis/Van	0.6	1.8	3.5
3. (R)	2.2	3.9	6.6
4. (S)	2.4	4.5	7.9
5. Tuzla/Canakkale	3.6	6.6	11.5
6. (T)	5.2	8.5	12.9
7. Dikili/Izmir	5.3	11.5	23.3
8. (P)	8.8	44.6	116.5
9. Seferihisar/Izmir	8.9	13.8	23.3
10. (U)	10.4	13.1	16.7
11. Simav/Kutahya	21.9	35.6	54.5
12. Germencik/Aydin	24.6	43	70.6
13. (X)	31.2	45.3	66.9
14. (Y)	50.5	83.9	133.6
15. Salavatli/Aydin	63.0	119.3	214.8
16. Kizildere/Denizli	94.2	112.2	133.9
17. (Z)	161.8	264.1	401.2

Power generation simulation results of 17 geothermal fields are shown in Figure 2 in arithmetic summation and probabilistic summation formats. From the probabilistic summation the MW_e values for P10, P50 and P90 were determined to be 710, 849 and 1032, respectively. For a reference temperature of 15 ^oC, the thermal energy power (MW_t) values of 17 fields for P10, P50 and P90 were also estimated to be 20 313, 24 694 and 32 246.

Our previous paper (Basel et al., 2009) reported the results based on eleven high temperature fields and indicated an estimate of the power generation potential as 453 MW_e and the thermal energy as 13 876 MW_t for P10 values. Therefore, the addition of six fields considered in this current updated work increased the power generation potential and the thermal energy to 710 MW_e and 20 313 MW_t, respectively.

The Monte Carlo Simulation approach was also utilized to estimate the geothermal energy potential for 41 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 Table 7 and Figure 3 as P10, P50 and P90 values of geothermal potentials for individual fields. As can be seen from Table 7 and Figure 3, 41 fields have 4 502, 5 098 and 5 812 MW_t values for P10, P50 and P90, respectively.

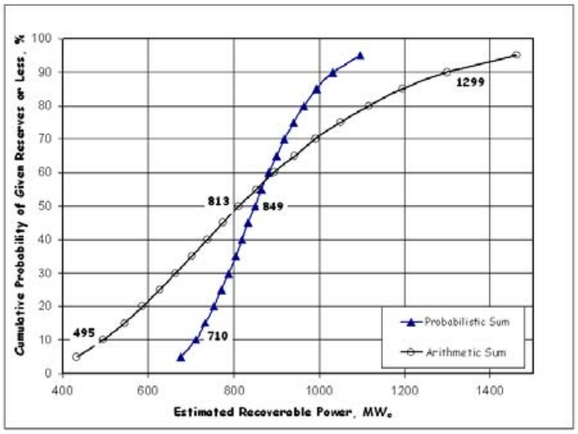

Figure 2: Monte Carlo Simulation results for power generation.

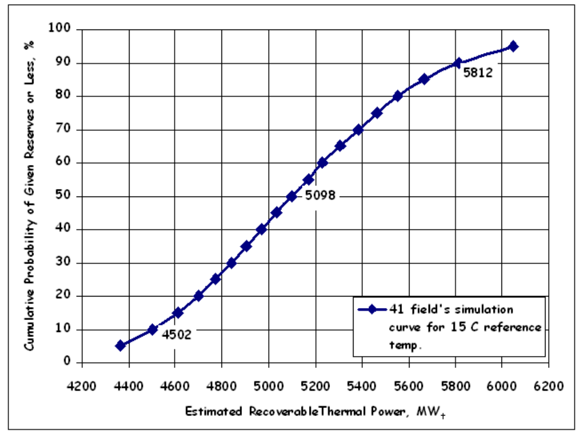

Figure 3: Monte Carlo Simulation results for district heating fields.

For the 55 fields studied so far, the combined thermal energy power (MW_t) values for P10, P50 and P90 are 23 566, 27 919 and 35 503 for a reference temperature of 15 ^oC, respectively.

The frequency of both P10 value intervals (when the reference temperature is 15^{o}C) and the minimum temperature value intervals for 55 fields investigated are shown in Figure 4 and Figure 5, respectively.

Table 8: Direct use potentials of 55 geothermal fields of Turkey.

Field's Name	P10	P50	P90	Field's Name	P10	P50	P90
1. Simav/Kutahya*	671	1055	1578	22. Bergama/Izmir	31	58	104
2. Dikili/Izmir*	353	576	869	23. Ayas/Ankara	29	69	150
3. Saphane/Kutahya	185	291	419	24. Kizilcahamam/Ankara	28	50	85
4. Omer-Gecek/Afyon	157	235	312	25. Gonen/Balikesir	26	46	80
5. Kestanbol/Canakkale	140	295	576	26. Yenice/Denizli	25	45	78
6. Gediz/Kutahya	102	164	250	27. Guzelyurt-S.hisar/Aksaray	21	41	69
7. Cesme/Izmir	95	153	236	28. Sorgun/Yozgat	23	39	62
8. Pasinler/Erzurum	88	185	344	29. Bayramic/Canakkale	21	39	70
9. Karahayit+Pamukkale/Denizli	69	125	216	30. Salihli/Manisa	20	34	55
10. Hıdırlar/Canakkale	65	109	171	31. Armutlu/Yalova	19	32	54
11. Kula/Manisa	57	103	174	32. Kuzuluk/Sakarya	17	31	53
12. Sandıklı/Afyon	53	98	170	33. Guzelyurt-Ilisu/Aksaray	16	33	59
13. Urganli/Manisa	53	101	178	34. Edremit	14	23	36
14. Cobanhamami/Ankara	50	110	218	35. Gure/Balikesir	14	27	49
15. Banaz/Usak	50	86	143	36. Heybeli/Afyon	13	28	54
16. Diyadin/Agri	50	96	174	37. Cekirge/Bursa	10	19	33
17. Kukurtlu/Bursa	49	82	129	38. Yerkoy/Yozgat	8	14	23
18. Golemezli/Denizli	45	82	140	39. Kırsehir	6	11	19
19. Ziga/Aksaray	43	76	125	40. Hisarkoy/Bigadic	5	16	39
20. Kozaklı/Nevsehir	40	71	120	41. Demirci/Manisa	4	9	17
21. Balcova/Izmir*	38	75	145				

* Suitable both for direct and indirect usage.

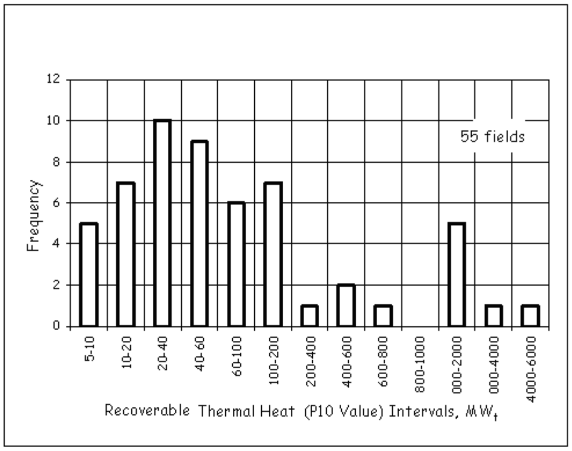

Figure 4: P10 value intervals Monte Carlo Simulation results for investigated 55 fields.

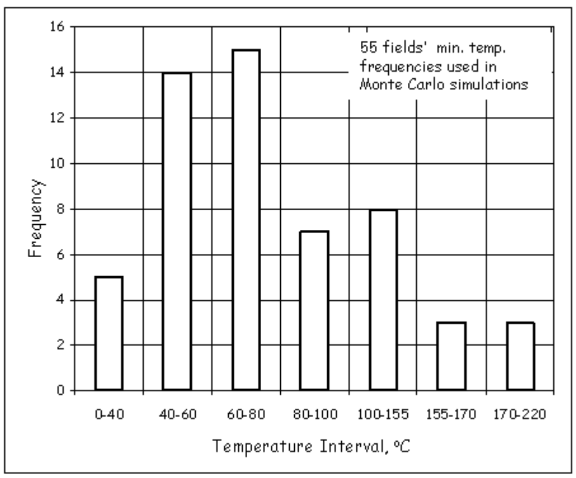

Figure 5: Temperature value intervals Monte Carlo Simulation results for investigated 55 fields.

Our previous paper (Basel et al., 2009) reported the results based on a total of 27 fields and indicated an estimate of the thermal energy potential as 14 387 MW_t for P10 values. We evaluated 28 more fields in last year. Therefore, the addition of 28 fields considered in this current updated work increased the thermal energy potential to 23 566 MW_t.

Results obtained from the Monte Carlo Simulation as discussed above differ from apparent capacity results. Here, capacities and potentials must not be confused. Apparent capacity results while reflect the identified capacities of all geothermal occurrences discovered in Turkey considering measured flow rate and temperature data of the produced fluids 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 20%, 17% and 14% for the P10, P50 and P90 values, respectively.

SUBSURFACE TEMPERATURE DISTRIBUTION MAPS FOR TURKEY

To detect hot regions, subsurface temperature distribution maps are constructed at various depths (500 m and 1000 m) both for Turkey and some local regions using geo-statistical methods. We used ESRI-Arc Gis software.

Two data sets were used to produce the maps. The data set which has 432 data points obtained mostly from the petroleum, natural gas, and geothermal wells with a depth of at least 1 km is called as Data Set 1. This data set is constructed by processing Mihcakan et al. (2006) gradient values and also using the new and updated data on geothermal wells.

The second set which has 555 data points called Data Set 2 is constructed by processing Ilkisik’s (2008), data which is obtained from 100/150 m shallow wells.

For the calculation of the temperature distributions in this study, the deep wells with more than 1 km depth and also 100/150 m shallow wells are selected (used) and the gradient values are both interpolated and extrapolated wherever required to calculate the temperature. In the calculations surface temperature is taken to be 15^{o}C.

In order to make a general assessment for the whole country, two data sets are combined and used as one data set. Ordinary kriging prediction map for 500 m depth (Figure 6) and standard error (uncertainty) temperature map (Figure 7) and also temperature prediction distribution map for 1000 m depth (Figure 8) are generated using this data set.

The whole country map, shows hot Aegean Region, relatively a hot region in central Anatolia and also illustrates recent volcanic activity areas in central and eastern Anatolia where volcanoes were formed.

Another whole country map (Figure 9) is generated only using Data Set 1. It is believed that the deep values could represent more accurate temperature distributions so Data Set 1 is used. Although the generation of temperature distribution map is not totally completed, it provides a good snapshot with which to illustrate the dominant promising areas and gives readers some information.

After the generation of whole country maps, we focused on the generation of regional maps. Local maps for Thrace (Figure 10) and Southeastern Anatolia (Figure 11) are generated using Data Set 1. Some relatively hot spots appear in maps of Southeastern Anatolia related to semi thermal areas formed in that basin. On the other hand, such occurrences related to hydrothermal resources can be found in Thrace basin.

Notice that the maps are generated for guidance only and are not the final depictions. As new data information added, these maps will gain certainty in time

CONCLUSIONS

The following results have been obtained in this study:
1) The estimate of Turkey's geothermal resource potential of rocks shallower than 3 km is $3\pm1\text{x}10^{23}$ J with the most likely value.
2) 17 high temperature (over 100 ^{o}C) fields investigated for indirect uses have values for P10, P50 and P90 of 710, 849 and 1032 MW_e for a reference temperature of 100 ^{o}C, respectively.
3) Assessment based on Monte Carlo Simulation study indicates that for the 55 fields studied so far, the combined thermal energy (MW_t) values for P10, P50 and P90 are 24, 28 and 36 thousand for a reference temperature of 15 ^{o}C, respectively.
4) The temperature distribution maps at 500 and 1000 m are constructed both for whole country and regionally.
5) The total apparent geothermal capacity of identified fields is 4800 MW_t and 4500 MW_t based on a reference temperature of 15 ^{o}C and 20 ^{o}C, respectively.

In this paper we presented current and updated results of country's geothermal energy apparent capacity and potential. 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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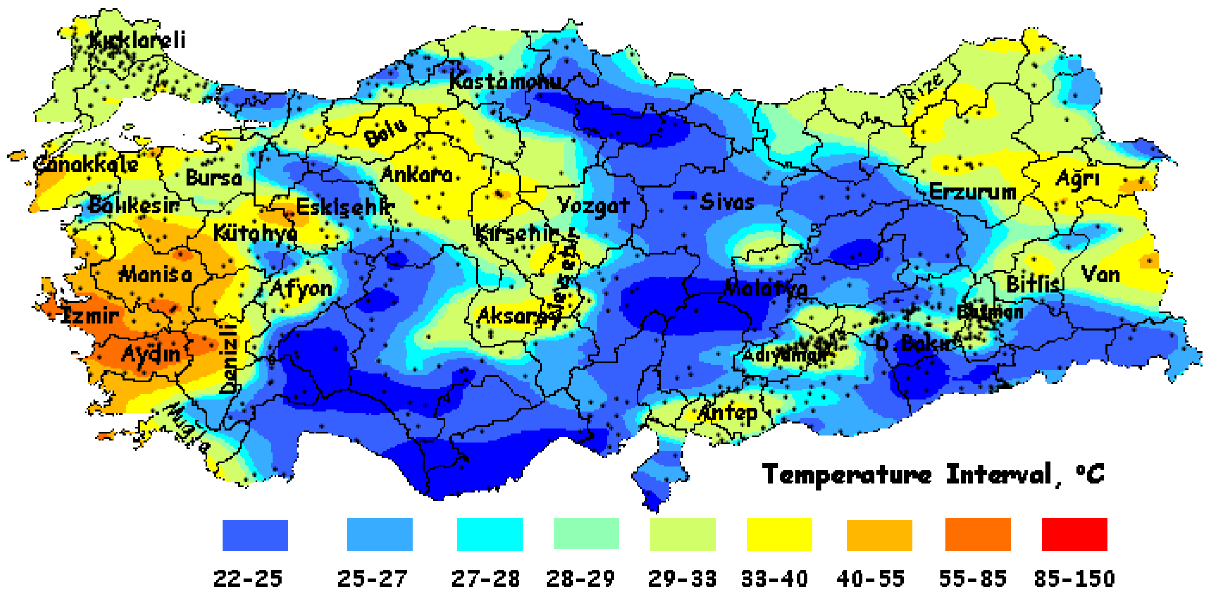


Figure 6: 500 m depth temperature distribution map with kriging interpolation (Data Set 1+ Data Set II).

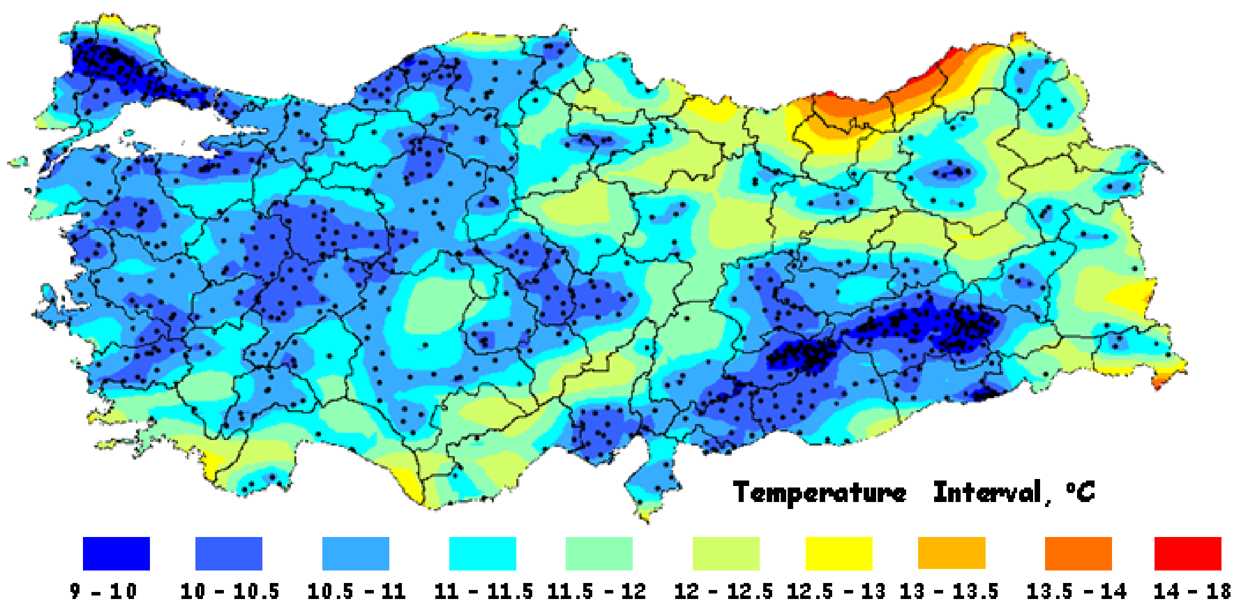


Figure 7: 500 m depth temperature prediction standard error distribution map (Data Set 1+ Data Set II).

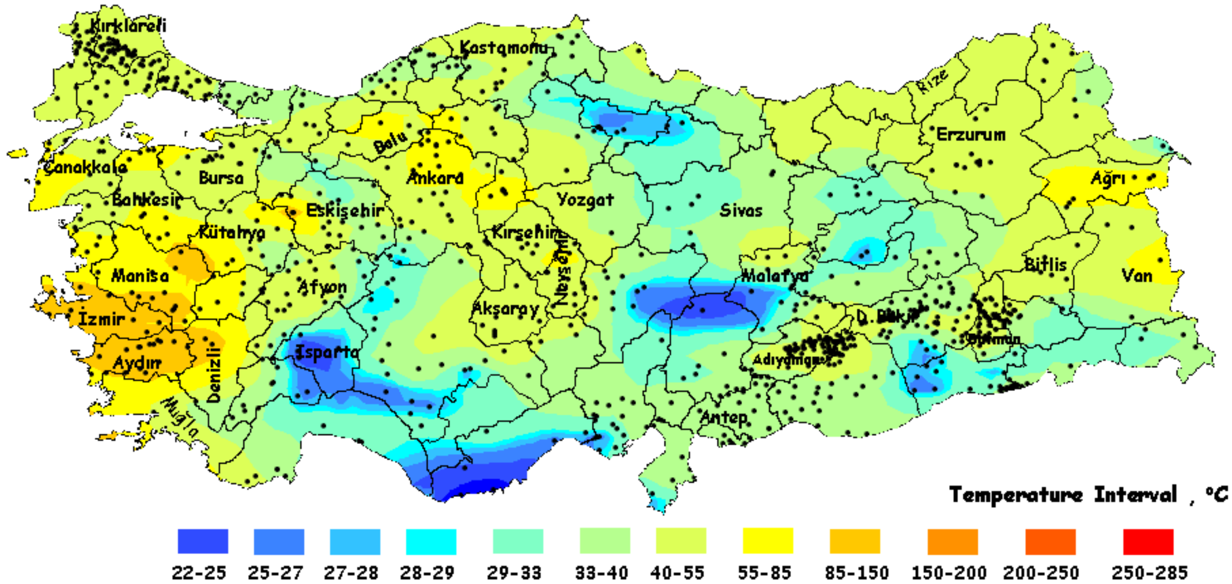


Figure 8: 1000 m depth temperature distribution map with kriging interpolation (Data Set 1+ Data Set II).

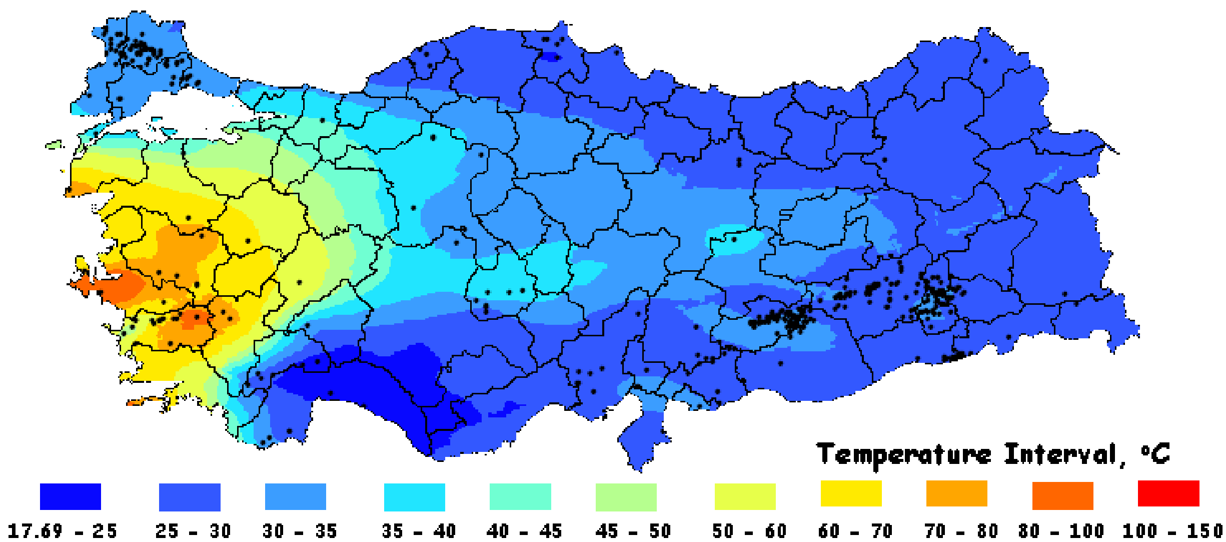
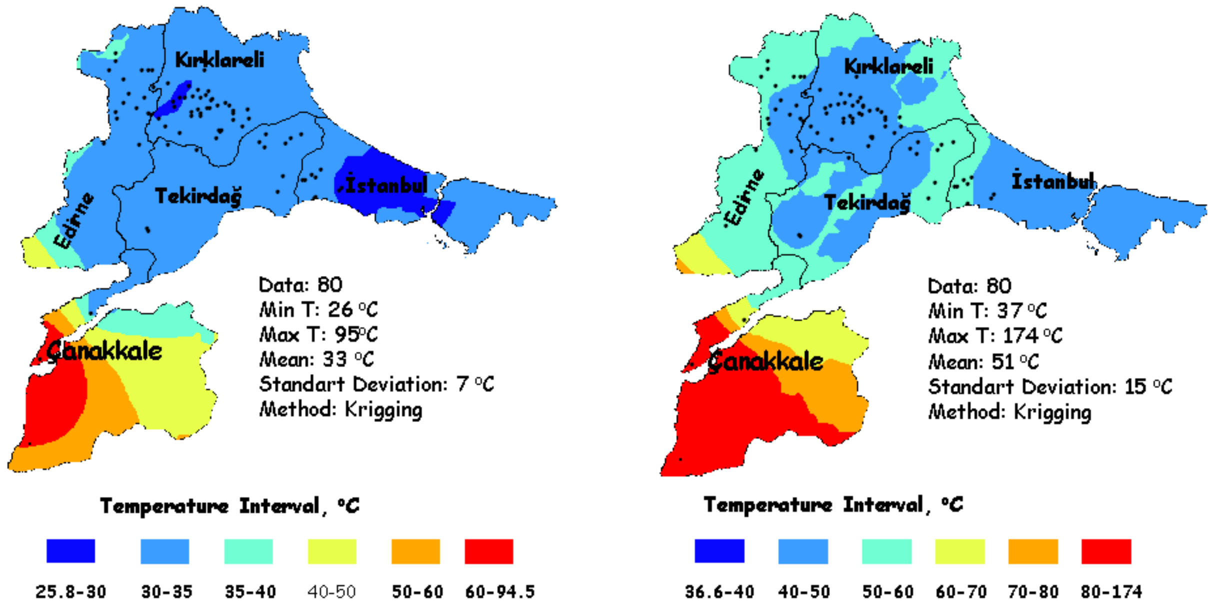
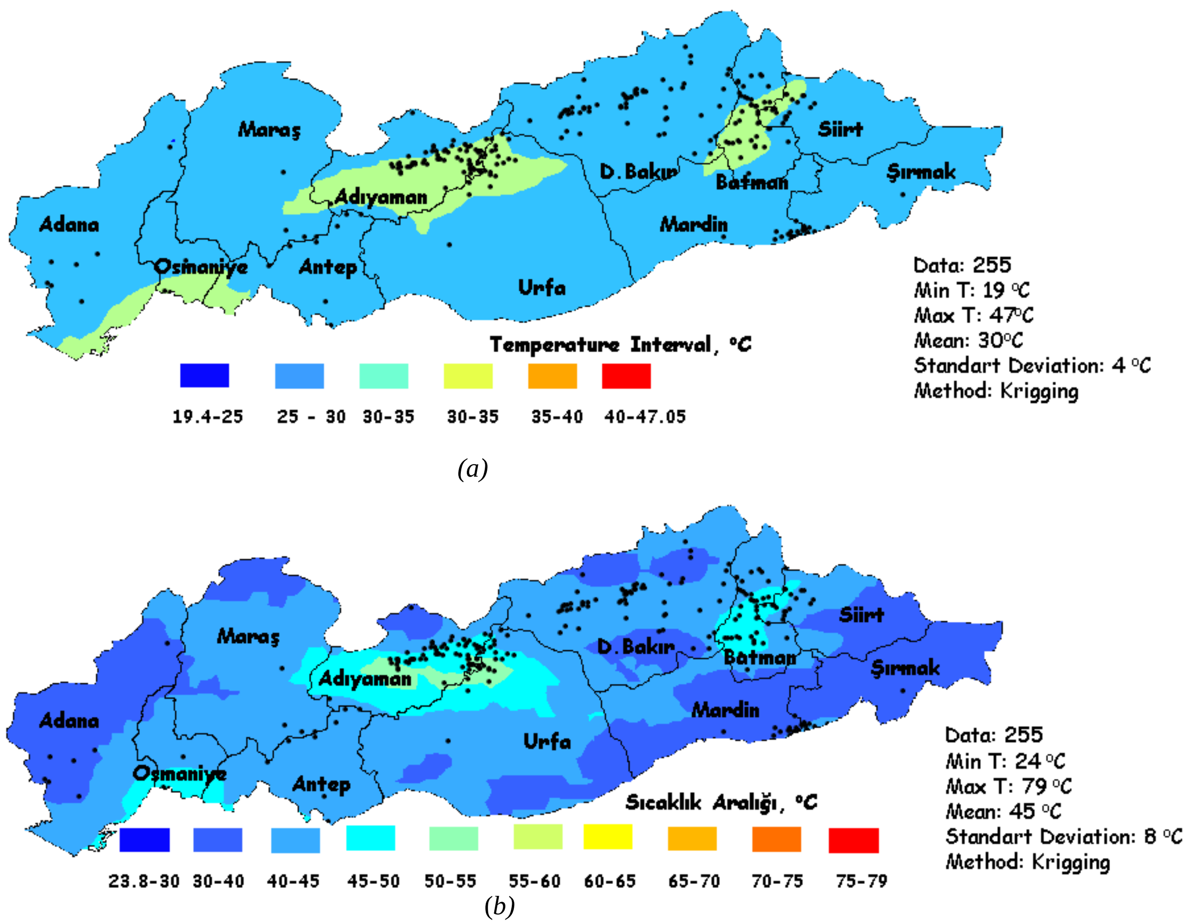


Figure 9: 500 m depth temperature distribution map with kriging interpolation (Data Set 1: 432 values used).



(a) (b)

Figure 10: 500 m (a) and 1000 m (b) depth temperature distribution maps of Thrace Region.



(a)

(b)

Figure 11: 500 m (a) and 1000 m (b) depth temperature distribution maps of South Eastern Anatolia Region.