

Importance of geothermal energy and its environmental effects in Turkey

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ABSTRACT

Geothermal energy, a relatively benign energy source when compared with other energy sources due to reduction in greenhouse gas emissions, is used for electricity generation and direct utilization. Turkey has a place among the first seven countries in the world in the abundance of geothermal resources, but it has only used about 4% of its potential. The paper presents the status of energy needs and renewables, potential, utilization and the importance of geothermal energy in Turkey. It also gives a comparison between geothermal energy and other energy sources regarding environmental issues. It is estimated that if the geothermal heating potential alone in Turkey is used, 5 million residences will be heated and as a result, releases of 48 million ton/year CO₂ emissions into the atmosphere will be prevented. In addition to this, if the other geothermal potential (i.e. electricity) is used it will provide considerable environmental benefits. Therefore, it is expected that geothermal energy development will significantly speed up in the future.

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1. Introduction

The majority of energy produced in the world today is obtained from fossil fuels, i.e. coal, petroleum, natural gas, and nuclear energy. In addition, sustainable and environmentally friendly resources, such as hydroelectric and geothermal, sunlight, wind, biogas, and wood, are also utilized [1].

With increasing awareness of the detrimental effects of the burning of fossil fuels on the environment, there has been an increasing interest worldwide in using clean and renewable energy sources, such as geothermal energy [2]. Geothermal energy, one of the most promising among renewable energy sources, has proven to be reliable, clean and safe, and therefore, its use for power production, and heating and cooling is increasing. It is a power source that produces electricity with minimal environmental impact [3–5]. Geothermal energy, hydropower, solar energy, wind power and biomass energy are the major renewable energy resources for Turkey in the future. Provided that geothermal energy, which has a considerable potential in Turkey, is used in electricity generation, besides heating and greenhouses, the energy problem in Turkey will be remarkably solved [6]. Turkey has a place among the first seven countries in terms of the abundance of geothermal resources around the world [7]. The estimated total geothermal potential in Turkey is about 31,500 MW_t for direct use

and 4500 MW_e for power generation. However, only 4% of this potential has been utilized so far [8].

The paper presents the status of energy needs and renewables, potential, utilization and the importance of geothermal energy in Turkey. It also gives a comparison between geothermal energy and other energy sources regarding environmental issues.

2. Turkey's energy needs and renewables

Turkey has almost all kinds of energy resources, but it is an energy importing country; more than half of the energy requirement has been supplied by imports. The high level of dependence on imported petroleum and natural gas is the dominant factor in Turkey's pattern of energy consumption. Turkey's primary energy sources include hydropower, geothermal, lignite, hard coal, oil, natural gas, wood, animal and plant waste, solar and wind energy [9,10]. Table 1 shows Turkey's primary energy production and consumption in 2005 and 2006. In 2006, the primary energy production and consumption reached 26.763 million tons of oil equivalent (Mtoe) and 98.138 Mtoe, respectively. Fossil fuels provided about 89.3% of the total energy consumption in 2006, with oil (33.2%) in the first place, followed by natural gas (29.4%) and coal (26.7%). While the share of petroleum in the consumption of commercial primary energy increased 1.12% from 2005 to 2006, the share of natural gas in the consumption of commercial primary energy grew 16.75% from 2005 to 2006. Turkey hasn't utilized nuclear energy yet [11]. The Turkish coal sector, which includes hard coal as well as lignite, accounts for nearly one half of the country's total primary energy production, with lignite being the

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Table 1
Turkey's primary energy production and consumption [12].

Energy source	Production		Consumption		Increase (2005–2006) in consumption Percentage
	Year 2005	Year 2006	Year 2005	Year 2006	
Fossil fuels (Mtoe)	14.425	16.211	79.075	87.586	+10.76
Oil	2.395	2.284	32.192	32.551	+1.12
Natural gas	0.816	0.839	24.726	28.867	+16.75
Coal (hard coal and lignite)	11.214	13.088	22.157	26.168	+18.10
Nuclear	–	–	–	–	–
Renewables (Mtoe)	10.124	10.552	10.124	10.552	+4.23
Hydro	3.483	3.886	3.483	3.886	+11.57
Geothermal	0.926	1.081	0.926	1.081	+16.74
Solar	0.385	0.403	0.385	0.403	+4.68
Wind	0.005	0.011	0.005	0.011	+120
Combustible renewables and wastes	5.325	5.171	5.325	5.171	–2.89
Total (Mtoe)	24.549	26.763	89.199	98.138	+10.0

main domestic energy source at 11.545 Mtoe in 2006. The renewables collectively provided 10.7% of the primary energy consumption, mostly in the form of combustible renewables and wastes (5.3%), hydropower (about 4.0%), geothermal (1.1%), and a small amount of other renewable energy resources (approximately 0.3%) [12].

In Turkey, electricity is produced by thermal power plants consuming coal, lignite, natural gas, fuel oil, and geothermal energy and hydropower plants. Turkey's electricity production was about 176,300 GWh in 2006, compared to 2814 GWh in 1960 (Table 2). Most of the electricity was produced by natural gas (about 45.8%), followed by hard coal and lignite (26.4%), renewables (25.4%), and oil (2.4%) in 2006 [13].

Turkey has substantial renewable energy resources. Renewables especially hydropower make the second-largest contribution to domestic energy production after coal. The installed capacity and the electricity production between 1960 and 2006 for some new and renewable energy sources, such as hydropower, combustible renewables and waste, geothermal, and wind energy are given in Table 3, where the data were compiled from statistical reports of the Turkish Electricity Transmission Company (TEİAŞ). The total electricity production from renewables in 2006 was 44,618.5 GWh. By far the largest contribution (about 99.15%) came from hydropower, but 0.35% came from combustible renewables and waste, and 0.5% from geothermal and wind. A study hasn't been carried out on the electricity production from other new renewables such as solar energy, wave and tidal energy. It was apparent that, in 2006, wind and geothermal energy were in the leading position

Table 2
Turkey's production of electricity by source [13].

Energy source	Years							
	1960	1970	1980	1990	2000	2004	2005	2006
Fossil fuels (GWh)	1773	5425	11,792	34,315	93,714	104,360	122,120	131,682
Hard coal + imported coal	1008	1382	912	621	3819	11,998	13,246	14,217
Lignite	533	1442	5049	19,561	34,367	22,450	29,946	32,433
Fuel oil	233	2600	5831	3942	9311	7670	5483	4341
Natural gas	–	–	–	10,192	46,217	62,242	73,445	80,691
Nuclear	–	–	–	–	–	–	–	–
Renewables (GWh)	1042	3199	11,484	23,228	31,208	46,339	39,837	44,618
Total production (GWh)	2815	8623	23,275	57,543	124,922	150,698	161,956	176,300
Net consumption (GWh)		7308	20,398	46,820	98,296	121,142	130,263	143,071

among renewables except for hydropower with regard to the total installed capacity (81.9 MW_e).

In Turkey, the primary energy sources and their consumptions between 2005 and 2025 are illustrated in Fig. 1. Primary energy consumption is expected to increase from 119 Mtoe (million tons of oil equivalents) in 2005 to 229 Mtoe by 2015 and to 535 Mtoe by 2025 [14]. According to 2004 data, Turkey produced 24.33 Mtoe/year from its own primary sources and consumed 86.20 Mtoe/year of primary energy. It is expected that by the year 2020, primary energy production will be 65.65 Mtoe, while primary energy consumption will be 309.5 Mtoe.

As can be seen in Fig. 1, it is expected that the energy resource having the most important rate in 2025 will be coal, with approximately 56%. The renewable energy source, the largest amount in 2025, will be hydropower energy (1.95%), while geothermal energy will have 1.01% of Turkey's primary energy consumption.

3. Geothermal energy potential and its usage in Turkey

Turkey is located on the Alpine–Himalayan orogenic belt and the Miocene or younger grabens are developed as the result of this orogeny. Turkey is surrounded by seas on three sides: the Black Sea to the north, the Marmara Sea and Aegean Sea to the west and the Mediterranean Sea to the south. Preliminary data show that the Marmara and Aegean regions of Turkey are rich in geothermal energy, which can be used for electricity production. Turkey is a country with significant potential in geothermal energy. Resource assessments have been made many times by the General Directorate of Mineral Research and Exploitation (MTA). Turkey has a place among the world's first seven countries with respect to the abundance of its geothermal resources [6,15,16].

Widespread volcanism, fumarole hydrothermal alterations, and the existence of more than 1000 hot and mineral water springs up to 100 and 140 °C in geothermal fields with a temperature range of 40–232 °C have been discovered in Turkey [17].

In spite of geothermal energy being a relatively new energy source for Turkey, when compared with other energy sources, it is utilized for various purposes, such as for electricity production, space heating and touristic installations. About 87.5% of the total geothermal potential is appropriate for thermal use (temperature <200 °C) and the remainder for electricity production (temperature >200 °C) [18]. A recent estimate of the geothermal potential of Turkey gives the total potential resources for direct use in excess of 31,500 MW_t. These figures for the potential cover both known and unknown resources (theoretical potential). It is estimated that the identified geothermal resources will be 200 MW_e for electricity generation (resource temperature higher than 200 °C) and in excess of 3293 MW_t for direct use (resource temperature lower than 200 °C) [19].

Geothermal energy in Turkey can be utilized in various forms, such as electricity generation, direct use, space heating, heat pumps, greenhouse heating and industrial usage. Currently in Turkey, hydropower and biomass are mostly in use, and geothermal is in the third place. Geothermal electricity generation has a minor role in Turkey's electricity capacity, as low as 0.10%, but the projections foresee an improvement to 0.32% by the year 2020. Opposing electricity generation, geothermal heat capacity is improving faster.

In 2005, the geothermal energy use of Turkey amounted to about 119.7 GWh/year of electricity and 6900.5 GWh/year for direct use [20,21]. Figs. 2 and 3 present the 2005 data in pie-chart form in percentages. Most of the development in direct use has been in district heating, which now serves 103,000 residences (827 MW_t and 7712.7 TJ/year), and in individual space heating (74 MW_t and 816.8 TJ/year) [22,23]. A total of 800,000 m² of greenhouse is heated by geothermal fluids (192 MW_t and 3633 TJ/year).

Table 3
Status of electricity production from renewables [12,13].

Energy source	Electricity production									
	1960	1970	1980	1990		2000		2005		2006
	GWh	GWh	GWh	GWh	%	GWh	%	GWh	%	
Hydropower	1002	3033	11,348	23,148	99.7	30,879	98.9	39,561	99.3	44,244
Geothermal and wind	–	–	–	80.1	0.3	108.9	0.3	153.4	0.39	220.5
Combustible renewables and waste	40.5	165.7	135.7	–	–	220.2	0.7	122.4	0.31	154.0
Total	1042.5	3198.7	11,483.7	23,228.1	100.0	31,208.1	100.0	39,836.8	100.0	44,618.5
Installed capacity										
	1960	1970	1980	1990		2000		2005		2006
	MW	MW	MW	MW	%	MW	%	MW	%	
Hydropower	411.9	725.4	2130.8	6764.3	99.7	11,175.2	99.7	12,906.1	99.73	13,062.7
Geothermal and wind	–	–	–	17.5	0.3	36.4	0.4	35.1	0.27	81.9
Combustible renewables and waste	–	–	–	–	–	–	–	–	–	41.3
Total	411.9	725.4	2130.8	6781.8	100.0	11,211.6	100.0	12,941.2	100.0	13,185.9

Geothermal heated pools used for bathing and swimming account for a capacity of 402 MW_t and utilize 12,677.4 TJ/year. About 120,000 tonnes of liquid carbon dioxide and dry ice are produced annually at the Kizildere power plant. By the year 2010 Turkey aims at having 500 MW_e dedicated to electricity generation and 3500 MW_t for space heating. Heat pumps are not being used at present, because of the high cost of electricity production [20].

It is clear that the present use of geothermal energy is a very small fraction of the identified geothermal potential. Turkey could make use of just 4% of its geothermal source potential so far. When Turkey uses all of the total geothermal potential it can meet 12.7% of the total energy needs (heat + electricity) from geothermal energy [21]. So, it is clear that Turkey should accelerate the use of geothermal energy for both electricity generation and direct use in the near future.

4. Importance of geothermal energy in Turkey

Today, at some locations around the country, geothermal energy is used to generate electricity, or geothermal heat is used directly for applications such as space heating, aquaculture, and industrial processes [24]. While geothermal energy is available at all times throughout the year, the availability of other renewable energy sources is in general much lower.

The country with the most extensive use of geothermal energy is Iceland, which obtains 50% of its total primary energy use from geothermal energy. Geothermal energy provides 86% of all space heating in Iceland and about 16.5% of the electricity generation (the remainder is hydropower) [3]. If geothermal energy usage is

considered in Turkey, by 2005, 0.014% of geothermal energy for electricity generation and the rest of it for other applications were used. Table 4 shows the ratio of geothermal electricity generation of some countries in the total electricity production [25,26]. As can be realized in this table, in Turkey, electricity generated from geothermal is only 0.1% of the total electricity generated in the country.

Turkey is poor in fossil fuel resources but rich in renewables such as geothermal, solar, wind, biomass and hydropower. Geothermal resources of the country are widespread but the favorable reserve for heating and generating electricity is limited and even this limited reserve has not yet been used [10,15]. First of all, geothermal energy for Turkey is a clean and domestic energy source; so its usage should be enhanced. Besides, geothermal energy is much cheaper compared to the other fossil fuels and other renewable energy sources in Turkey. Geothermal energy in Turkey is 7.7%, 21.6%, 27.7%, 9.8%, 56.9%, and 9.8% cheaper than hard coal, lignite, fuel oil, natural gas, and wind, respectively. When the total geothermal energy potential of Turkey is used, geothermal energy will be able to provide 12.7% of Turkey's energy needs. Therefore, it is evaluated that it will decrease 7.8% of the energy import of Turkey by 2020.

The contribution of geothermal energy to the Turkish National Economics is nearly 1.4 billion dollars with all of electricity generation, geothermal district heating, CO₂ production, and balneological utilization etc. Also the total employment in this sector will be 40,000 people. It is estimated that the annual net domestic supplementary budget provided when all of Turkey's total geothermal potential is evaluated is 20 billion dollars [8,23].

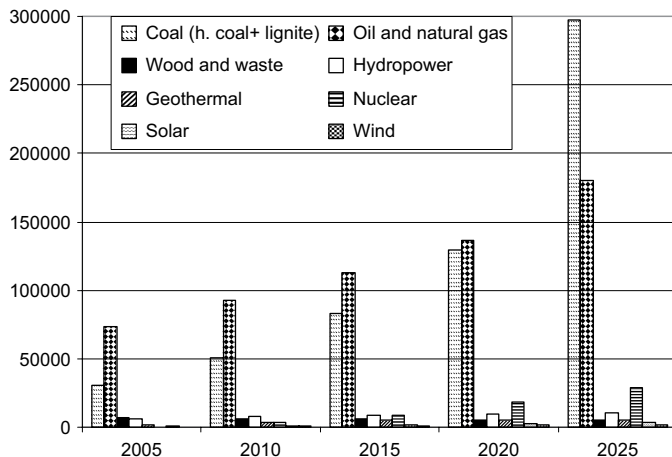


Fig. 1. Primary energy consumption of Turkey between 2005 and 2025 (Mtoe) [14].

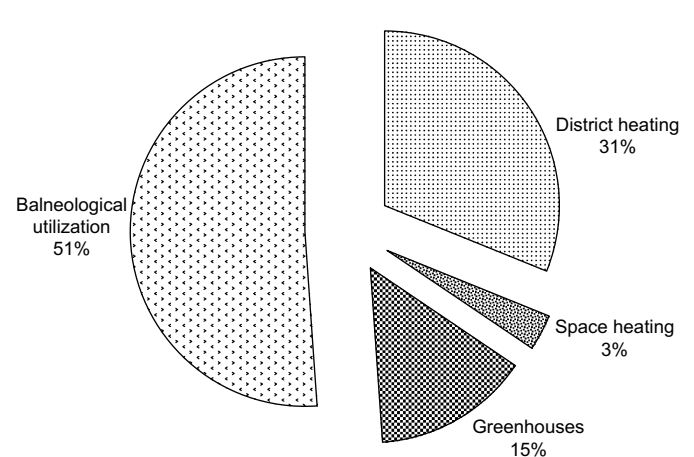


Fig. 2. Categories of Turkey's geothermal energy direct utilization in % for 2005 [20].

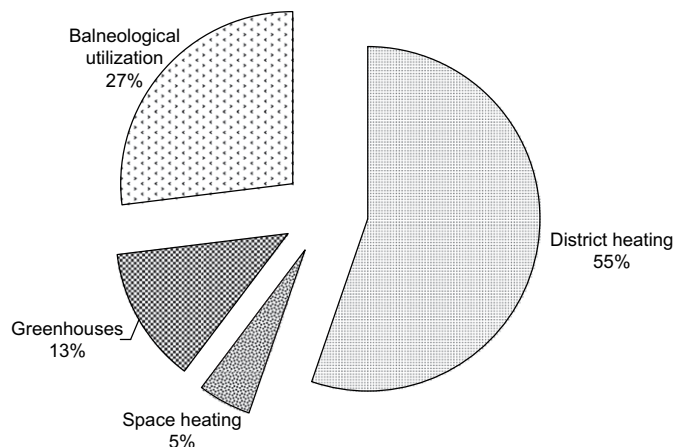


Fig. 3. Categories of Turkey's geothermal energy direct utilization capacity in 2005 [20].

5. Environmental effects of geothermal energy in Turkey

Air pollution in geothermal fields may be caused by the discharge of geothermal gases in steam. Geothermal fluids contain a variable quantity of gas, largely carbon dioxide with some hydrogen sulfide and smaller proportions of ammonia, mercury, radon and boron. Carbon dioxide, which is usually the major constituent of the gas present in geothermal fluids, and methane, a minor constituent, both require attention because of their role as greenhouse gases. Hydrogen sulfide probably causes the greatest concern as it has a noxious smell and is toxic in moderate concentrations. It has been observed that, as a result of geothermal field exploitation, the concentration of H_2S increases relatively more than the concentration of CO_2 , probably because of the higher reactivity of H_2S . If the climatic conditions of the surrounding environment are suitable, H_2S will be oxidized to SO_2 causing global acid raining. Both carbon dioxide and hydrogen sulfide are heavy gases and tend to concentrate in pits and lows; so careful monitoring is needed to ensure that hazardous conditions do not develop locally. Geothermal gases will also have an impact on the biology of an area [27,28].

In Turkey, the amounts of pollutants depend on the geological conditions of different fields. Most of the chemicals are

Table 4
Ratio of geothermal electricity generation of some countries in the total electricity production [25,26].

Country	Total production of electricity (GWh)	Production of geothermal electricity (GWh)	Ratio of electricity generated from geothermal resources, %
USA	4,081,468	14,870	0.4
Philippines	52,863	9822	18.6
Indonesia	112,926	6315	5.6
Mexico	218,654	6282	2.9
Italy	293,865	5341	1.8
Japan	1,047,198	3484	0.3
New Zealand	41,111	2764	6.7
Iceland	8500	1406	16.5
El Salvador	4077	966	23.7
Costa Rica	7566	920	12.2
Kenya	4864	787	16.2
Nicaragua	2655	271	10.2
Turkey	140,581	89	0.1
EU-25	3,118,560	5434	0.2
OECD	9,938,334	34,329	0.3
IEA	9,528,371	26,641	0.3
World	16,741,884	53,735	0.3

Table 5
Environmental impacts as source type [9,30].

Source	Contribution to emissions, air pollution, and climate change	Contribution to water pollution	Waste	Visual impacts	Noise	Impacts on habitat and living life
Fossil fuels	+	+	+	-	+	+
Solar	-	-	-	+	-	-
Wind	-	-	-	+	+	+
Geothermal	-	+	-	-	+	+
Hydrogen	-	+	-	-	-	-
Ocean-wave	-	+	-	+	+	+
Biomass	+	-	+	+	-	+

concentrated in the disposal water that is routinely reinjected into drill holes and thus not released into the environment. The concentrations of the gases are usually harmless, and the removal of hydrogen sulfide from geothermal steam is a routine matter in geothermal power stations where the gas content is high [3,29].

Geothermal energy is considered to be a clean energy source if it is compared to nuclear and fossil fuels. Environmental impacts of the resources used in energy generation are shown in Table 5 [30]. The relative amounts of greenhouse gas emissions from the electricity of geothermal origin are only a fraction of the amounts coming from fossil fuel, and are of the same magnitude as most other renewable energy sources, such as hydro and solar energy (Fig. 4). Although the CO_2 emission values are 900–1300 g/kWh in coal, 500–1250 g/kWh in natural gas, 20–250 g/kWh in solar energy, and 20–50 g/kWh in wind energy, it is only 20–35 g/kWh in geothermal energy [8,27,31]. No nitrogen oxides and sulfur oxide emissions will be formed by geothermal because fossil fuels are not used in geothermal heating systems and geothermal electricity generation plants.

Geothermal energy has an important role in environmental protection because it greatly reduces releases of the main air pollutants such as CO_2 and SO_2 emissions into the atmosphere. Recoverable avoid additional CO_2 emissions values (if the whole of the potential of geothermal energy in Turkey is used) are reported in Table 6 [32]. It can currently be seen in the table, using geothermal heating capacity in Turkey is equal to 117,000 residences space heating (for 2007 year) and therefore, 1.1 million ton/year CO_2 emissions releases into the atmosphere are prevented. This value is also equal to the exhaust emissions of 650,000 vehicles. It is estimated that if the geothermal heating potential alone in Turkey is used, 5 million residences (30% of the total residences) will be heated and as a result, releases of 48 million ton/year CO_2 emissions into the atmosphere will be prevented.

In Turkey, as in the world, some significant progress such as treatment techniques of the waste fluid has been made to prevent environmental problems caused by geothermal energy usage. In addition, the reinjection of waste water into the underground is

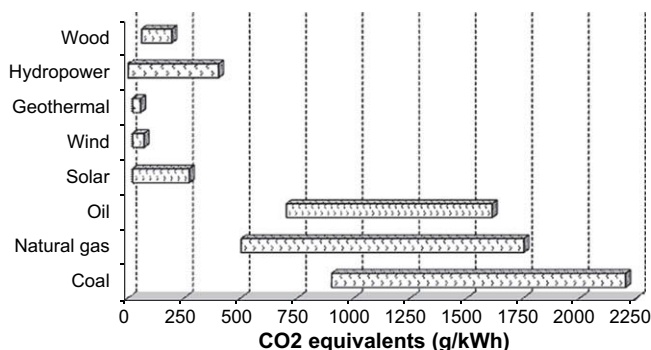


Fig. 4. Greenhouse gas emissions from various types of energy sources during the generation of electricity [8,27,31].

Table 6

Effect of geothermal energy into the avoiding of additional CO₂ emissions in Turkey [32].

Geothermal heating	Avoiding of additional CO ₂ emissions (tons/year)	Exhaust emissions equivalence of vehicles in January (vehicle)
Existing 117,000 residences equivalence	1,100,000	650,000
Current applicable 1 million residences equivalence	8,000,000	5,000,000
Total heating potential 5 million residences equivalence	48,000,000	30,000,000

important for the protection of the environment and reservoir parameters. Therefore the reinjection applications in Turkey should be extended.

6. Conclusions

The main conclusions that can be drawn from the present study are listed below:

- The present use of geothermal energy is a very small fraction of the identified geothermal potential. Only 4% of the geothermal source potential of Turkey was used so far. When Turkey uses all of the total geothermal potential, it can meet 12.7% of the total energy needs.
- It was found that only 0.014% of geothermal energy was used for electricity generation by 2005 in Turkey. This amount is under the world average and should be increased to produce environmentally benign energy utilization.
- Geothermal energy can be prescribed as a much cleaner source of energy than conventional energies. The relative amounts of greenhouse gas emissions from the electricity of geothermal origin are only a fraction compared to the amounts coming from fossil fuels, and are of the same magnitude as most other renewable energy sources, such as hydro and solar energy.
- It is concluded that if the geothermal heating potential alone in Turkey is used, 5 million residences (30% of the total residences) will be heated and as a result, releases of 48 million ton/year CO₂ emissions into the atmosphere will be prevented.
- Due to it being renewable, reliable, clean, and a cheap domestic energy resource, development studies and investments in the geothermal sector should be encouraged and supported.

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