A Snapshot of Geothermal Energy Potential and Utilization in Turkey

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Abstract

Turkey is one of the countries with significant potential in geothermal energy. It is estimated that if Turkey utilizes all of her geothermal potential, she can meet 14% of her total energy need (heat and electricity) from geothermal sources. Therefore, today geothermal energy is an attractive option in Turkey to replace fossil fuels. Besides, increase in negative effects of fossil fuels on the environment has forced many countries, including Turkey, to use renewable energy sources. Also, Turkey is an energy importing country; more than two thirds of her energy requirement is supplied by imports. In this context, geothermal energy appears to be one of the most efficient and

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effective solutions for sustainable energy development and environmental pollution prevention in Turkey. Since geothermal energy will be used more and more in the future, its current potential, usage, and assessment in Turkey is the focus of the present study. The paper not only presents a review of the potential and utilization of the geothermal energy in Turkey but also provides some guidelines for policy makers.

Keywords: *geothermal energy, renewable sources, Turkey*

1. Introduction

The combined effect of the widespread depletion of fossil fuels and the gradually emerging consciousness about environmental degradation has given priority to the use of conventional and renewable alternative energy sources such as geothermal, wind, hydro, solar and bioenergy sources.

The energy sources can be split into three categories: fossil fuels, renewable sources, and nuclear sources. In this paper, the focus will be on renewable sources, specifically geothermal energy, in Turkey. However, before getting into details of geothermal energy use in Turkey, let me concentrate on the definition of “renewable source”. In this paper, an energy source is regarded as renewable if it has the following two distinctive qualifications:

- Carbon neutral,
- Derived from those natural, mechanical, thermal and growth processes that repeat themselves within our lifetime.

Based on this definition, examples of renewable energy sources include geothermal, wind, hydro, solar and bioenergy sources.

Geothermal energy is the energy contained as heat in the Earth's interior that can be used continuously for heating and electricity-generation. The origin of this energy is linked with the internal structure of our planet and the physical processes occurring there. This heat is brought to the near-surface by thermal conduction and by intrusion into the Earth's crust originating from great depths. Groundwater is heated to form hydrothermal resources. Use of hydrothermal energy is economic today at a number of high-grade sites. Hydrothermal resources are tapped by existing well-drilling and energy-conversion technologies to generate electricity or to produce hot water for direct use (house heating etc.). For generation of electricity, hot water at temperatures ranging from about 150 to 370°C is brought from the underground reservoir to the surface through production wells and is flashed to steam in special vessels by release of pressure. The steam is separated from the liquid and fed to a turbine engine, which turns a generator (Akpinar et al., 2007).

Italy was the first country to develop geothermal power commercially in 1914 at Larderello. Since then, use of geothermal power has been exponentially increasing at about 8.5% per year. For the last four decades geothermal energy has been produced commercially on the scale of hundreds of megawatts both for electricity generation and for direct use. In the early 2000s, geothermal resources have been identified in over 80 countries and there are quantified records of geothermal utilization in 58 countries in the world (Hepbasli ve Ozgener, 2004).

Turkey is located in the Mediterranean side of Alpine-Himalayan tectonic belt and, therefore, among the first seven countries of the world in terms of abundance of geothermal resources. The share of its potential used is, however, only about 2-3%.

To find out the development trends of the scientific studies in the field of renewable energies in Turkey, Celiktas et al. (2008) processed a total of 12,197 publications and as a result found 1,555 papers focusing on renewable energy sources in Turkey between 1980 and 2008. Among them, there are 72 papers on geothermal energy, out of which 10 are experimental studies, 25 are informational studies and remaining 37 are available system analysis. The study could not detect any paper on policy development in geothermal energy in Turkey. Since present article not only describes the development of geothermal energy in Turkey as of January 2009 but also provides some guidelines for policy development, it is an important contribution to existing literature. The rest of the study is organized as follows. Section 2 introduces the key indicators of Turkish economy and her energy sector. Section 3 describes the current status of geothermal energy in Turkey, while Section 4 focuses on geothermal energy economics. Following section presents an assessment of geothermal energy use, including its benefits and drawbacks. Then, some guidelines for policy makers are provided in Section 6 based on the findings of the study. Finally, Section 7 gathers the main conclusions derived from the paper.

2. Key indicators of Turkish economy and energy sector

The Republic of Turkey, located in Southeastern Europe and Southwestern Asia (that portion of Turkey west of the Bosporus is geographically part of Europe), has an area of about 780,580 sq km and a population of over 70 million (CIA, 2009). With its young population, growing energy demand per person, fast growing urbanization and economic development; Turkey has been one of the fast growing power markets of the world for the last two decades. Turkey is an energy importing country; more than two thirds of the energy requirement has been supplied by imports.

Turkey's dynamic economy is a complex mix of modern industry and commerce along with a traditional agriculture sector that still accounts for more than 35% of employment. It has a strong and rapidly growing private sector, yet the state still plays a major role in basic industry, banking, transport, and communication. Real GNP growth has exceeded 6% in many years, but this strong expansion has been interrupted by sharp declines in output in 1994, 1999, and 2001. The economy is turning around with the implementation of economic reforms, and 2004 GDP growth reached 9%, followed by roughly 5% annual growth from 2005-07. Inflation fell to 7.7% in 2005 - a 30-year low - but climbed back to 8.5% in 2007. Despite the strong economic gains from 2002-07, which were largely due to renewed investor interest in emerging markets, IMF backing, and tighter fiscal policy, the economy is still burdened by a high current account deficit and high external debt. In short, the economic fundamentals of Turkey are sound, marked by strong economic growth and foreign direct investment (CIA, 2009).

Turkey's population of more than 70 million is growing at an annual rate of 1.01% and expected to grow to 83.4 million in 2022. In response to the growth rates of population and consumption, Turkey's total final energy consumption (TFC) grew at an average annual rate of 9.6% over the last three decades. This average annual growth rate of TFC is projected to decrease to 5.4% between 2005 and 2010 and 7% between 2010 and 2020 (Evrendilek and Ertekin, 2003). Table 1 presents some important selected Indicators for Turkey (CIA, 2009).

[Table 1 goes here]

Turkey's primary energy sources include hydropower, geothermal, lignite, hard coal, oil, natural gas, wood, animal and plant wastes, solar and wind energy. In 2005, primary energy production and consumption has reached 23.6 million tonnes (Mt) of oil equivalent (Mtoe) and 85.2 Mtoe, respectively. Table 2 shows the Turkey's energy balance table in 2005. Fossil fuels provided about 88.2% of the total energy consumption of the year 2005, with oil (30.1%) in first place, followed by natural gas (26.7%) and coal (26.4%). Turkey has not utilized nuclear energy yet[1]. 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 (%44.4). The renewables collectively provided 11.9% of the primary energy, mostly in the form of combustible renewables and wastes (6.3%), hydropower (about 4%) and other renewable energy resources (1.6%) (IEA, 2009).

[Table 2 goes here]

As can be seen in Table 2, the general equilibrium of energy use and supply indicators shows that Turkey is dependent on imported resources very heavily. In 2005, 79.3% of the total energy supply was met by imports.

Turkey's total electricity production and installed capacity were 191.6 GWh and 41.7 GW, respectively, in 2007. The distribution of the produced electricity energy according to primary energy sources was as follows: natural gas 49.6%, coal 27.9%, hydropower 18.7%, oil 3.4%, **geothermal 0.08%** and wind 0.2%. Table 3 reflects the increasing reliance on natural gas[2] in the power sector. The share of natural gas power plants in installed capacity was about 31.56% in 2007. Likewise, natural gas had the largest share in gross electricity output in 2007 (TEIAS, 2009).

[Table 3 goes here]

3. Current status of geothermal energy

3.1. Geothermal energy in the world

Since the 1970s, rising concern for global environmental degradation have led to wide acceptance of sustainable development concept. Following its initial popularization, the concept of the sustainability has appeared in a wide range of forms in recent literature. Although different authors have given it a variety of meanings, sustainable development is best defined as *meeting the needs of the present generation without compromising the ability of future generations to meet their own needs* (WCED, 1987). In this context, sustainability is used to characterize the desired balance between economic growth and environmental preservation.

The Kyoto Protocol to the United Nations Framework Convention on Climate Change, agreed to in December 1997, marks an important turning point in efforts to promote the use of renewable energy worldwide. Since the original Framework Convention was signed at the Earth Summit in Rio de Janeiro in 1992, evidences of climate change have spurred many countries to increase their support of renewable energy. Even more ambitious efforts to promote renewables (including geothermal energy) can be expected as a result of the Kyoto pact, which includes legally binding emissions limits for industrial countries, and for the first time, specially identifies promotion of renewable energy as a key-strategy for reducing greenhouse gas emissions.

Actually, geothermal energy has been used for generation of electricity and heat for a century. The total geothermal electricity production in the world was 59.24 TWh in 2006 with the United States leading at 16.58 TWh and Philippines with 10.47 TWh (Table 4). Other major countries are Mexico, Indonesia, Italy, New Zealand, Japan and Iceland with between 6.69 and 2.63 TWh each. Iceland produces 26.5% of its electricity from geothermal sources while El Salvador, Philippines and Costa Rica do the same with

20.3%, 18.5% and 14% respectively. On average, 0.31 of all world electricity is produced from geothermal sources (IEA, 2008).

[Table 4 goes here]

Today, there are at least 76 countries with geothermal heating capacity and 24 countries with geothermal electricity. Most of the geothermal power capacity exists in USA, Philippines, Mexico, Italy, Indonesia, Japan and New Zealand. On the other hand, geothermal direct-heat utilization capacity nearly doubled from 2000 to 2005, an increase of 13 GW, with at least 13 new countries using geothermal heat for the first time. Iceland leads the world in direct heating, supplying some 85% of its total space-heating needs from geothermal sources. About half of the existing geothermal heat capacity exists as geothermal heat pumps, also called ground source heat pumps. These are increasingly used for heating and cooling buildings, with nearly 2 million heat pumps used in over 30 countries, mostly in Europe and the USA. The top ten countries in terms of installed capacity for heat extraction are listed, in descending order, in Table 5 together with the 10 countries with the greatest installed capacity for geo-electricity generation. As can be seen in the table, Turkey is the 5th richest country in the world in terms of non-electricity geothermal energy generation (Bilgen et al., 2008).

[Table 5 goes here]

In October 2005, European Union (EU) opened accession negotiations with Turkey, who has been an associate member of the EU since 1963 and an official candidate since 1999. There are many policies, directives, standards and norms in the EU designed to stimulate and support the geothermal energy use. The European Commission in its White Paper on Renewable Sources of Energy has set the goal of achieving a 12% penetration of renewables in the EU by 2010. One of the targets of the White Paper is to increase the EU electricity production from renewable energy sources from 337 TWh in 1995 to 675 TWh in 2010. Within this target the goal for geothermal energy is 1,000 MW of installed capacity for electricity generation (that could produce 7 TWh of electricity per year) and 5,000 MW for heat production (including heat pumps) in 2010. Moreover, in all European countries, production of electricity from renewable resources is supported. In many countries minimum price system is used widely, which requires an electricity utility to purchase a portion of its electricity requirement, named as green energy, at a minimum price defined. Legally defined minimum prices change according to the country; some of them are shown in Table 6 (Aras, 2003).

[Table 6 goes here]

Currently, Turkey is not required to comply with the EU norms but in the near future she will be obliged to do so in the course of accession negotiations[3].

3.2. Geothermal energy utilization and potential in Turkey

Turkey has significant potential for geothermal energy production, possessing one-eighth of the world's total geothermal potential. Much of this potential is of relatively low enthalpy that is not suitable for electricity production but still useful for direct heating applications (Evrendilek and Ertekin, 2003). Out of Turkey's total geothermal potential, around 94% is appropriate for thermal use (temperature less than 150°C) and the remainder for electricity production (temperature more than 150°C). The geothermal electricity generation capacity potential of Turkey is estimated at 2,000 MW (16 TWh/year) and a generation capacity of 550 MW that utilizes geothermal sources is expected by the year 2013. The main utilization of geothermal energy in Turkey, however, is in domestic heating, greenhouses, spas and thermal resorts. The overall geothermal heat generation potential of Turkey is about 31,500 MW. It is projected that, by the years 2010 and 2020, the total installed capacity will increase to 3,500 MW (500,000 residence equivalent, which is about 30% of the total residences in the country) and 8300 MW, (1,250,000 residence equivalent) for space heating, respectively (EIE, 2009).

The first geothermal researches and investigations in Turkey started by Turkish Mineral Research and Exploration Institute (MTA in Turkish initials) in 1960s. Since then, about 170 geothermal fields have been discovered by MTA, where 95% of them are low-medium enthalpy fields, which are suitable mostly for direct-use applications. Table 7 presents high-temperature geothermal fields suitable for conventional electricity generation in Turkey (EIE, 2009).

[Table 7 goes here]

Turkey's first commercial geothermal power plant is located at Denizli-Kizildere field. It was discovered by the MTA in 1968 and a power plant was installed there in 1984 with a capacity of 20.4 MW. Apart from power production capacity, Turkey has 827 MW district heating and 402 MW balneological utilization capacities together with a carbon dioxide production capacity of 120,000 tonnes per year. If she fully utilizes its geothermal potential, Turkey is capable of meeting 5% of her electricity need and 30% of heat requirement from geothermal sources, which corresponds to 14% of her total energy need (EIE, 2009).

On the other hand, there exist some barriers in Turkey for the exploitation of geothermal energy. These can be listed as follows:

- establishment of a structure at the institutional level, which requires a higher level of coordination and cooperation within and between institutions, agencies, institutes, and other stakeholders,
- insufficient available information about existing and possible future costs of geothermal energy utilization,
- insufficient detailed geothermal energy resource assessments and data banks pertaining to Turkey,
- insufficient credit facilities, particularly for small-scale projects,
- administrative and time-consuming obstacles for foreign investors,
- need for support for infrastructure and management know-how at a local level,
- insufficient participation by the private sector,
- need for staff with sufficient technical information,

- difficulties possibly encountered in planning, project feasibility, and project control activities,
- insufficient policy instruments in the sector,
- need for public acceptance and willingness,
- technology risks[4].

3.3. Current Turkish legislation on geothermal energy

Existing Turkish law and regulation with relevance to the use of renewable energy sources is limited to two pieces of legislation. One piece of legislation is the Electricity Market Licensing Regulation, and the second is the Law on Utilization of Renewable Energy Resources for the Purpose of Generating Electrical Energy (Law Number 5346, dated May 10, 2005). As indicated by the titles, these have been developed for the electricity sector. In both regulations, geothermal energy is included in the definition of renewable energy resource. There is no legislation currently existing for geothermal energy alone.

In Turkey, market based policies for renewables started in 1984 with third-party financing, excise and sales tax exemptions. Capital grants were offered in 2001. The Turkish government's approach to the deployment of renewables reveals its priorities to develop indigenous and renewable resources in conjunction with the expansion of privately owned and operated power generation from renewable sources. The build-own-transfer (BOT) and the build-own-operate (BOO) schemes were put in place in 1984 and financed major power projects (not limited to renewables) with the main objective of attracting private investors. BOT projects were granted a treasury guarantee. Although BOT and BOO approaches attracted significant investment, they also created large public obligations with the government covering the market risk through take-or-pay contracts. The BOT and BOO financing schemes ended in 2000 and were replaced in 2001 by financial incentives within the framework of the Electricity Market Law (Law Number 4628)[5].

According to the Electricity Market Licensing Regulation, promotion of renewable energy sources in the electricity market has been assigned to the Energy Market Regulatory Authority (EMRA). Specifically, the Regulation states that the issues assigned to the Energy Market Regulatory Authority are "*With regard to the environmental effects of the electricity generation operations, to take necessary measures for encouraging the utilization of renewable and domestic energy resources and to initiate actions with relevant agencies for provision and implementation of incentives in this field*". In this context, there are some incentives and regulations related to renewable energy sources. The incentives brought into existence based on the Electricity Market Licensing Regulation are given below:

- Entities applying for licenses for construction of facilities based on domestic natural resources and renewable energy resources shall pay only 1% of the total licensing fee.
- The generation facilities based on renewable energy resources shall not pay annual license fees for the first 8 years following the facility completion date indicated on their respective licenses.

- Turkish Electricity Transmission Company (TEIAS) and/or distribution companies shall assign priority for system connection of generation facilities based on domestic natural resources and renewable resources.

The aim of the Law on Utilization of Renewable Energy Resources for the Purpose of Generating Electrical Energy is to increase the use of renewable energy sources for generating electricity, as well as to diversify energy resources, reduce greenhouse gas emissions, assess waste products, protect the environment, and develop the necessary manufacturing sector for realizing these objectives. Specific incentives introduced in the law that are applicable to the use of geothermal power include:

- ***Obligation to purchase electricity from renewable energy sources:*** Each legal entity possessing a retail sale license shall be required to purchase renewable energy source-certified (RES-certified) electricity in an amount declared by EMRA.
- ***Purchasing of electricity from renewable energy sources with a higher price:*** Until the end of 2011, the applicable price for the electricity to be purchased in pursuance with the law within each calendar year shall be the Turkish average wholesale electricity price in the previous year determined by EMRA. However, this price shall be between 5 and 5.5 Eurocent/kWh. The Council of Ministers is entitled to raise this price up to 20% at the beginning of each year.
- ***Acquisition of land:*** In the case of utilization of property which is under the possession of Forestry or Treasury or under the sovereignty of the State for the purpose of generating electricity from the

renewable energy resources included in the law, these territories are permitted on the basis of its sale price, rented, given right of access, or usage permission by the Ministry of Environment and Forestry or the Ministry of Finance. A fifty percent deduction shall be implemented for permission, rent, right of access, and usage permission in the investment period.

4. Geothermal energy economics

Table 8 presents electricity generation costs by fuel type (Demirbas, 2008) and ranges of investment and generation costs are provided in Table 9 for renewable sources (IEA, 2003).

[Table 8 goes here]

[Table 9 goes here]

As can be seen from the tables, electricity produced from geothermal energy is in general still more costly than that from fossil fuels. However, the gap is almost closed. For instance, if we regard the cost of producing electricity from natural gas as 100 units, that from geothermal sources is 109.3 units. That is, geothermal power is only about 9.3% more expensive than power from natural gas. Moreover, among renewable sources, geothermal energy comes third (together with wind energy) after hydro and bio power as the least expensive power source.

The economics of geothermal power depends on several factors. Cost is primarily technology driven and is influenced by production technology. By far the most significant factors that contribute to geothermal energy value are related to the geothermal resource and the characteristics of the grid and the evolving market rules. As additional geothermal capacity is developed, these variables will be quantified more precisely.

A possible investor investing his/her money in geothermal energy, like any other investor, looks for a good return on his/her investment. To minimize the investment risk, he/she wants certainty in costs and revenues over the investment period. A geothermal power project is like a hydropower project - capital intensive but with a low running cost. A geothermal project is commercially viable only if it creates a positive net present value (NPV) over its economic life for the investors. This requires a guaranteed stream of revenue in the future from the power sales, and the risks in the steam supply from the geothermal resource must be manageable. Therefore, the selection of the exploitation process, power cycle, and power plant is critical to minimize capital cost and maximize power output. Risks are inherent in the resource and power plant development. Resource exploration risk is relatively high, with a corresponding higher return potentially at moderate investment. This type of risk is familiar to the mining and oil exploration companies. The steam field and power plant development risk is low. Most investors and bankers are familiar with this risk too. In geothermal power industry, the drilling stage is a major expenditure phase, with each well costing USD 750,000 to USD 3 million. Well outputs are highly variable, from a dry well to one that may produce 40 MW. Once production drilling starts, the aim is to produce electricity, and hence return on investment, as soon as possible. Currently, a geothermal power project costs between USD 1,000 and USD 2,000 per kW depending on the quality of the steam. An electricity unit cost of 5 to 8 cents/kWh is achievable. This is very competitive compared with conventional thermal and hydropower stations (Lee, 2004).

5. Evaluation of geothermal energy use

5.1. Benefits of geothermal energy use

Clean, domestic and renewable energy is commonly accepted as the key for future life, not only in Turkey but also in the world. This is primarily because renewable energy resources have some advantages compared to fossil fuels. In this context, geothermal energy appears to have formidably positive environmental properties. The most important gain of geothermal energy utilization is the environmental benefit of displacing fossil fuel usage and a reduction in any adverse environmental impacts that are caused by fossil fuel consumption. Measured gaseous pollutants emissions for various fuel types such as CO_2, CH_4, NO_x and SO_2 are presented in Table 10. The figures shown in Table 10 are based on the lifecycle assessment technique, and indicate gaseous emissions emitted during the whole process (Kone and Buke, 2007). As indicated by Table 10, the smallest environmental loads are due to hydropower, wind, geothermal and nuclear power plants. Among organic fuels, ecologically the most advantageous one is natural gas, although it is behind nuclear power and hydropower, while coal and oil burning is still the source of significant environmental pollution. During the operation of power plants with renewable energy sources such as photovoltaic (PV) cells, wind, geothermal or hydropower plants, there are no emissions and the environmental loads are small. The main environmental burdens for renewable energies are due to the balance of life cycle - namely, due to the material and equipment production and power plant construction.

[Table 10 goes here]

The environmental benefits of geothermal energy are felt locally, regionally and globally. Geothermal energy can displace power from fossil fuel-powered plants, and thereby help to improve local air quality, mitigate regional effects such as acid rain, and reduce greenhouse gas emissions globally. Power plants emit pollutants as a by-product of power generation, but also may account for further emissions in connection with plant construction, operation, and decommissioning. For example, the mining and transport of fuel are themselves energy-intensive activities, with associated emissions and environmental impacts. Geothermal energy compares favorably to traditional power generation on this metric as well. Lifecycle CO_2 emissions per unit of power produced by a geothermal power station are about 2.5% of that for coal plants and about 5.4% of that for natural gas facilities.

Today, we clearly see the necessity for seriously considering renewable energy sources when we examine the environmental impact associated with other possible sources. The abundant fossil fuels, such as coal, are often damaging to the environment throughout the fuel cycle, from mining to processing to consumption. Fossil fuels also carry the threat of global climate modification through increased discharge of carbon dioxide, particulates and other materials. Nuclear energy, while imposing no threat of climate modification, is associated with serious problems, such as waste disposal, accidents and weapons proliferation. Nuclear energy also releases waste heat into the environment through on site cooling processes and through transportation and use of the electricity it produces. In short, continuous uses of fossil fuels are bound to pollute the atmosphere and consequently unwanted greenhouse and climate change effects will come to dominate every part of the earth. It is, therefore, vital to exploit clean energy resources, and for many nations in the world to try to assess their environmentally friendly, clean energy resources such as geothermal energy.

In recent years, Turkey has begun to ignore the importance of energy usage based mainly on domestic sources. Today, about 79% of the Turkey's energy consumption is met by imports. The reliance on import resources - particularly on natural gas - to such an extent threatens the essentials of the sustainable development model seriously. In this context, geothermal energy contributes to Turkey's energy diversification strategy.

Moreover, geothermal systems have a number of positive characteristics. They are simple, safe, and adaptable systems with modular 1-50 MW plants capable of providing continuous baseload, load following or peaking capacity. Geothermal power also presents an opportunity to move towards more decentralized forms of electricity generation, where a plant is designed to meet the needs of local customers, avoiding transmission losses and increasing flexibility in system use; which in turn provides an opportunity to increase the diversity of power generation plants, and competition in electricity generation. Furthermore, geothermal power plants require relatively little land, taking up only a fraction of that needed by other energy sources. Other land uses can coexist with geothermal plants with little interference or fear of accidents. Finally, geothermal facilities have neither huge piles of ash nor barrels of radioactive waste. Containment barriers associated with most fossil-fuelled power plants are non-existent in current geothermal power plant designs.

5.2. Drawbacks of *and* obstacles to geothermal energy use

Nonetheless, there are many barriers and obstacles that slow down the progress of geothermal energy diffusion into power industry. Some of these barriers have general character that stay before power industry as a whole. Others possess narrow character typical only for geothermal energy. Among formers are:

- The necessity for regulatory reforms in energy sector;
- Creation of a kind of effective “High National Energy Council”;
- The active participation of the relevant factors in the energy policy making process;
- The integration of domestic energy sectors in international market and privatization;
- Close cooperation of the state bodies with scientific organizations, private sector, public associations, political parties, and interest groups in the process of planning;

- Necessity of developing various contemporary scientific models for energy planning.

The latter barriers include:

- Definition of the specific place of renewable energy sources in the overall energy politics;
- Reinforcement of infrastructure of electrical networks at geothermal locations as a matter of priority;
- Revision of legal framework for independent power producers to address the realities of the present and demands of the future.

In addition to above mentioned ones, some other specific problems associated with geothermal energy utilization are presented below.

Generally speaking, geothermal power production cost is currently higher than that of the classic fuels (see Table 8). However, it is better to keep in mind that cost comparisons are highly subject to fluctuations and the continuous efforts for the advances in geothermal power production technologies may make this cost relationship more favorable for geothermal energy.

Also, there exist some environmental problems associated with geothermal energy, such as water shortages, air pollution, and waste disposal. Environmental impacts of the sources used in energy generation are shown in Table 11 (Akpinar et al., 2007). In table, it is used "+" in case of being stated impact of source. It is used "-" in the event of not being or little being stated impact of source. It is examined whether or not there is only an impact of source. Therefore, marks in the table are relative.

[Table 11 goes here]

The wastes produced by geothermal systems include toxic metals. Water shortages are also an important limitation in arid regions. Geothermal systems produce hydrogen sulfide, a potential air pollutant: however, this product could be processed and removed for use in industry. Moreover, geothermal plants produce noise pollution during construction, e.g. by drilling of wells and the escape of high-pressure steam during testing. Noise is usually negligible during operation with direct-heat applications. However, electricity generation plants produce some noise from the cooling tower fans, the steam ejector and the turbine. Furthermore, geothermal plants are often located in areas of high scenic value, where the appearance of the plant is important. Fortunately, geothermal power plants take up little area and, with careful design they can blend well into the surrounding environment. Overall, the environmental costs of geothermal energy appear to be minimal relative to those of fossil fuel systems.

Final two concerns relates to renewability of geothermal energy and its impact on some species' habitat. It is sometimes argued that geothermal energy sources are limited and decline over the last 40-100 years globally (Evrendilek and Ertekin, 2003). In the development stage of geothermal systems (e.g., removing trees), not only entire loss of some species' habitats may occur but also some indirect impacts may emerge because of disturbance (i.e., the animals will no longer reside near the development area).

6. Guidelines for policy makers

The overall objective of energy-related policies should be ensuring sufficient, reliable and affordable energy supplies to support economic and social development, while protecting the environment. Therefore, when choosing energy fuels, it is essential to take into account economic, social and environmental consequences. In the past, environmental impacts of energy resources were ignored or not foreseen, while energy policies focused on adequate supply of energy to assure high rates of economic growth. Today, besides the economic issues, particular importance should be assigned to environmental factors associated with the choice of energy sources.

In Turkish case, as fossil fuel energy becomes scarcer, Turkey will face energy shortages, significantly increasing energy prices, and energy insecurity within the next few decades. In addition, Turkey's continued reliance on fossil fuel consumption will contribute to accelerating rates of domestic environmental quality and global warming. For these reasons, the development and use of renewable energy sources and technologies are increasingly becoming vital for sustainable economic development of Turkey (Bilen et al., 2007).

Prospective policy instruments and guidelines for Turkey may include the following.

- One of the most important barriers preventing widespread use of renewables in Turkey is the lack of a coherent national energy plan in which the role of renewables is well explained. Therefore, first of all, Turkey must develop and publicize a rational and coherent energy policy and an action plan; stating short, middle and long term aims, actions and reasons that justify them. Then, the specific place of renewable energy sources in the overall energy politics of Turkey should be defined. Also, a kind of effective "High Energy Council" must be set up to provide a higher level of coordination and cooperation within and between institutions, agencies, institutes, and other stakeholders. If not, it is not possible for Turkey to develop in a sustainable way and all other guidelines given below lose their meanings.
- Turkey's geothermal resources are considerable, but they have not yet been systematically explored. Geothermal wells drilled to date in Turkey, which has 170 geothermal fields, are few in number. More geothermal wells should be drilled for extending geothermal applications throughout the country.
- Heating by geothermal energy in Turkey is the cheapest compared to conventional heating systems and has thereby gained wide acceptance among consumers. Besides, the cooling applications of geothermal energy are very limited. Therefore, they should be encouraged throughout the country. For instance, by heating 61,000 residence equivalent by geothermal energy in Turkey, approximately 600,000 tons of CO_2 emission is not discharged to the atmosphere, which is equivalent to avoiding 340,000 cars from the traffic (as of

peak emission amount in January) and 700,000 ton per year oil saving (Kaygusuz and Kaygusuz, 2004).

- Existing Turkish legislation on geothermal energy should be developed in compliance with EC directives.
- In Turkey, there is no specific law on geothermal energy that regulates the utilization of geothermal sources of the country in their full potential. However, there is a geothermal draft law. It is expected that geothermal energy development will significantly speed up in the country if such a law becomes effective.
- Existing legislation to encourage the generation of geothermal power in Turkey is not appropriate. The Law on Utilization of Renewable Energy Resources for the Purpose of Generating Electrical Energy (Law No. 5346) designates 5.0–5.5 Euro cent/kWh as the price of renewable electricity in Turkey. However, currently this support is not enough and even spot market prices are sometimes higher than 5.0–5.5 Euro cent/kWh. Therefore, Turkey should determine renewable energy price expressed as a percentage of Turkish average electricity wholesale price (TAEWP). For instance, it may be stated that price of electricity from renewable sources equals to %150 of TAEWP.
- Turkey should establish a target (e.g., 15%) for the penetration of renewable energy sources into the domestic energy consumption by a given year. It could also include a separate but integrated target for geothermal energy alone, potentially with interim targets to ensure the country stays on track with the goal.
- A program should be prepared to support the advancement in technology with regard to both the supply and demand sides of

geothermal energy. Turkey should also invest to the geothermal energy technology both for using its geothermal potential more cheaply in the long run and for supplying job opportunity to the people.

- In the light of the data available, it seems that Turkey is a suitable country to establish geothermal systems. Projects, subject to regional conditions, should be started in regions that offer productive geothermal energy potential.
- More detailed geothermal energy resource assessments and data banks pertaining to Turkey should be prepared.
- Administrative and time-consuming obstacles for foreign investors should be eliminated.
- Geothermal power stations should be located away from wildlife refuges and residential areas to prevent public opposition. Internationally accepted requirements for noise conditions should also be developed in order to reduce noise pollution.

Finally, although the immediate priority of Turkey should be to speed the transition from the reliance on non-renewable fossil fuels to reliance on renewable energy sources, policy makers must be aware of the fact that renewable sources are alone not enough to meet the rapidly increasing energy demand in Turkey. Therefore, policy makers should seriously consider some other alternative energy sources, including nuclear power.

7. Conclusion

Geothermal energy provides a clean, renewable energy source that could dramatically improve our environment, economy and energy security. Geothermal energy generates far less (almost none) air emissions than fossil fuels and decreases the reliance on imported energy. Today, in most ways, geothermal energy has come of age; the technology has improved, the economics has become more appealing, and substantial progress has been achieved in reducing environmental impacts.

Turkey is an energy-importing country. In order to be less dependent on other countries, Turkey needs to use its sustainable sources. From this point of view, geothermal energy is a very attractive choice, since it is economical, sustainable, environmental friendly and a familiar energy source in Turkey. Furthermore, Turkey has several advantages for the use of geothermal energy in terms of its location and geological background. However, today, in Turkey, the domestic consumption of geothermal energy is lagging, mainly due to economic barriers, lack of legislative and regulatory framework and poor infrastructure.

While specific policies and regulations are recommended here, it is also important for efficiency and effectiveness that communication and mechanisms for coordination/cooperation between ministries (i.e. energy, and environmental) and other related institutions (e.g. EMRA) be improved.

The private sector, which has the capacity to mobilize needed funds, must be motivated to participate in geothermal energy and other renewable energy development. The process of liberalization, restructuring, and privatization in the Turkish energy sector[6] is also vital; which will assist in creating a favorable environment for investment in geothermal energy.

To sum up, in Turkey, geothermal energy represents a secure domestic source of energy that is not subject to the price fluctuations and supply uncertainties of imported petroleum and natural gas. Future supply of geothermal energy depends on energy prices and technical progress, both of which are driven by energy policy priorities.

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Footnotes

[1] For a more in depth discussion of nuclear energy in Turkey, see Erdogdu (2007b).

[2] Turkey imports 96.9% of her natural gas consumption.

[3] For a more detailed discussion of EU-Turkey relations, see Erdogdu (2002).

[4] While improved technology may be able to battle some of the elevated investment costs of geothermal energy, technology risks remain. Some relevant technology is proven, however a lot of technology remains in research, development, and demonstration phases. This technology risk may be considered unacceptable to some investors.

[5] Before the Electricity Market Law, the price of energy was decided as a result of negotiations between the energy production companies and the state, which is the buyer. For more information on the subject, see Erdogdu (2005).

[6] For more details on the subject, see Erdogdu (2007a).

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Table 1. Selected indicators for Turkey

Indicator	Value
Population (million)	71,892,808 (July 2008 est.)
Population growth rate	1.01% (2008 est.)
GDP (purchasing power parity)	$853.9 billion (2007 est.)
GDP (official exchange rate)	$663.4 billion (2007 est.)
GDP real growth rate	4.5% (2007 est.)
GDP per capita (purchasing power parity)	$12,000 (2007 est.)
GDP per capita (official exchange rate)	$9,228 (2007 est.)
Electricity production	192 GWh (2007)
Electricity Consumption / Population (kWh/capita)	2,671 (2007)
CO_2 Emissions[a] (Mt of CO_2)	218.93 (2005)

[a] CO2 Emissions from fuel combustion only. Emissions are calculated using IEA's energy balances and the Revised 1996 IPCC Guidelines.

Table 2. Energy balances for Turkey (2005)

Supply and Consumption	Coal	Crude Oil	Petroleum Products	Gas	Nuclear	Hydro	Geothermal, Solar, etc,	Combustible Renewables and Waste	Electricity	Heat	Total[a]
Production	10,482	2,231	0	738	0	3,402	1,397	5,356	0	0	23,607
Imports	11,720	23,223	10,419	22,127	0	0	0		55	0	67,543
Exports	0	0	-5,498	0	0	0	0	0	-155	0	-5,653
International Marine Bunkers[b]	0	0	-1,067	0	0	0	0	0	0	0	-1,067
Stock Changes	268	151	436	-80	0	0	0	0	0	0	775
TPES	**22,470**	**25,605**	**4,290**	**22,785**	**0**	**3,402**	**1,397**	**5,356**	**-100**	**0**	**85,205**
Statistical Differences	194	8	-13	0	0	0	0	0	0	0	189
				-							-
Electricity Plants	-9,585	0	-994	11,157	0	-3,402	-86	-32	13,310	0	11,948
CHP Plants	-104	0	-221	-1,460	0	0	0	-1	618	850	-318
		-									
Petroleum Refineries	0	25,671	26,201	0	0	0	0	0	0	0	530
Coal Transformation	-1,889	0	0	0	0	0	0	0	0	0	-1,889
Other Transformation	0	58	-54	0	0	0	0	0	0	0	4
Own Use	-296	0	-1,557	-102	0	0	0	0	-697	0	-2,653
Distribution Losses	-51	0	0	-19	0	0	0	0	-2,068	0	-2,138

TFC	**10,739**	**0**	**27,652**	**10,047**	**0**	**0**	**1,311**	**5,323**	**11,063**	**850**	**66,982**
Industry sector	**8,266**	**0**	**4,320**	**2,708**	**0**	**0**	**121**	**0**	**5,218**	**850**	**21,483**
Transport sector	**0**	**0**	**13,629**	**106**	**0**	**0**	**0**	**0**	**65**	**0**	**13,799**
Other sectors	**2,471**	**0**	**5,964**	**6,747**	**0**	**0**	**1,189**	**5,323**	**5,781**	**0**	**27,476**
Residential	2,471	0	2,960	4,783	0	0	1,189	5,323	2,660	0	19,387
Commercial and Public Services	0	0	0	1,963	0	0	0	0	2,767	0	4,730
Agriculture / Forestry	0	0	3,005	0	0	0	0	0	345	0	3,349
Fishing	0	0	0	0	0	0	0	0	9	0	9
Non-Energy Use	**0**	**0**	**3,739**	**486**	**0**	**0**	**0**	**0**	**0**	**0**	**4,225**
- of which											
Petrochemical Feedstocks	0	0	770	486	0	0	0	0	0	0	1,256

(in thousand tonnes of oil equivalent (ktoe) on a net calorific value basis)

[a] Totals may not add up due to rounding.

[b] International marine bunkers are not subtracted out of the total primary energy supply for world totals.

Table 3. Installed capacity and electricity generation in Turkey (2007)

Fuel Type	**Installed Capacity (MW)**	**%**	**Electricity Generation (GWh)**	**%**
Natural Gas	13.177	31,56	95.025	49,61
Hydropower	13.829	33,12	35.851	18,72
Coal	10.097	24,19	53.431	27,89
Oil	1.952	4,67	6.483	3,38
Geothermal	**30**	**0,07**	**156**	**0,08**
Wind	355	0,85	355	0,19
Others	2.309	5,53	258	0,13
Total	**41.748**	**100**	**191.558**	**100**

Table 4. Distribution of world gross geothermal electricity production in 2006 (TWh)

	Geothermal	% of World Capacity	% of Total	Total Production
World	**59,24**	**100,00**	**0,31**	**19.014,22**
United States	16,58	27,99	0,39	4.300,10
Philippines	10,47	17,67	18,46	56,73
Mexico	6,69	11,29	2,68	249,65
Indonesia	6,66	11,24	5,00	133,11
Italy	5,53	9,33	1,76	314,12
New Zealand	3,40	5,74	7,81	43,52
Japan	3,08	5,20	0,28	1.100,36
Iceland	2,63	4,44	26,49	9,93
Costa Rica	1,22	2,06	14,02	8,70
El Salvador	1,14	1,92	20,36	5,60
Russia	0,46	0,78	0,05	995,79
Nicaragua	0,31	0,52	10,47	2,96
Portugal	0,09	0,15	0,18	49,04
Turkey	**0,09**	**0,15**	**0,05**	**176,30**
Kenya	0,09	0,15	1,39	6,48
Others	0,80	1,35	-	-

Table 5. Top ten installed geothermal energy capacity in the world in 2005

Country	Non-electricity production (MW)	Percentage of world total	Country	Electricity production (MW)	Percentage of world total
USA	8,670	29.22	USA	2,564	28.39
Sweden	3,840	12.94	Philippines	1,978	21.90
China	3,687	12.43	Mexico	953	10.55
Iceland	1,804	6.08	Italy	810	8.97
Turkey	**1,229**	**4.14**	Indonesia	797	8.83
Austria	1,134	3.82	Japan	535	5.92
Japan	822	2.77	New Zealand	434	4.81
Hungary	694	2.34	Iceland	232	2.57
Italy	682	2.30	Costa Rica	163	1.80
Switzerland	582	1.96	El Salvador	151	1.67
Rest of world	6,524	21.99	Rest of world	414	4.58
World total	**29,668**	**100.00**	**World total**	**9,031**	**100.00**

Table 6. Minimum price of renewable electricity in some European countries (Euro cent/kWh)

Country	**Price**
Netherlands	9.6 - 9.9
France	8.4
Austria	7.8
Portugal	7.5 - 7.9
Greece	6.4
Spain	6.3 - 7.5
Germany	6.2 - 8.5
Turkey	**5.0 – 5.5**

Table 7. Geothermal fields suitable for conventional electricity generation in Turkey

Geothermal field in Turkey	Temperature
Aydin-Germencik	232 °C
Manisa-Salihli-Gobekli	182 °C
Canakkale-Tuzla	174 °C
Aydin-Salavatli	171 °C
Kutahya-Simav	162 °C
Izmir-Seferihisar	153 °C
Manisa-Salihli-Caferbey	150 °C
Aydin-Yilmazkoy	142 °C
Izmir-Balcova	136 °C
Izmir-Dikili	130 °C

Table 8. Electricity generation costs by fuel type (cent/kWh)

Power source	**Minimum**	**Maximum**
Large hydro	3.0	13.0
Small hydro	4.0	14.0
Municipal solid wastes	4.2	6.3
Biomass	4.2	7.9
Natural gas	4.3	5.4
Coal	4.5	7.0
Agricultural residues	4.5	9.8
Wind	4.7	7.2
Geothermal	**4.7**	**7.8**
Hydraulic	5.2	18.9
Nuclear	5.3	9.3
Solar thermal hybrid	6.0	7.8
Wave/tidal	6.7	17.2
Energy crops	10.0	20.0
Solar PV	28.7	31.0

Table 9. Ranges of investment and generation costs in 2002 and 2010 ($/kW)

	Low investment costs		**High investment costs**		**Low generation costs**		**High generation costs**	
	2002	**2010**	**2002**	**2010**	**2002**	**2010**	**2002**	**2010**
Small hydro power	1,000	950	5,000	4,500	2-3	2	9-15	8-13
Solar photovoltaic power	4,500	3,000	7,000	4,500	18-20	10-15	25-80	1840
Concentrating solar power	3,000	2,000	6,000	4,000	10-15	6-8	20-25	10-12
Biopower	500	400	4,000	3,000	2-3	2	10-15	8-12
Geothermal power	**1,200**	**1,000**	**5,000**	**3,500**	**2-5**	**2-3**	**6-12**	**5-10**
Wind power	850	700	1,700	1,300	3-5	2-4	10-12	6-9

Table 10. Main gaseous pollutants (g/kWh)

Fuel type	CO_2	CH_4	NO_x	SO_2
Nuclear	17	-	0.047	0.072
Geothermal	**21**	**0.059**	**-**	**-**
Hydropower	32	0.135	0.056	0.055
Wind	38	0.169	0.055	0.071
Biomass, wood burning only	-	-	0.350	0.087
Solar (PV cells)	319	0.883	0.408	0.494
Natural gas	386	1.076	0.351	0.125
Oil	760	4.216	0.622	0.314
Coal	838	4.716	0.696	0.351

Table 11. Environmental impacts as source type

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