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Evaluation of Turkey's Geothermal Energy Resources in terms of Exergy Analysis

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ABSTRACT

Turkey has a place among the first seven countries in the world with the abundance of geothermal resources, but has only used about 7% of its potential. The exergy analysis is a powerful tool for the design, analysis, and classification of thermal systems like geothermal resources. In this study, specific exergy index for examined field was calculated between 0.026 and 0.790 and sustainability index was found between 1.420 and 2.782. This study aims to point out resource use efficiency in Turkey and to promote this subject by putting emphasis on Turkey's geothermal energy potential with an exergy example.

1. INTRODUCTION

Turkey has a place among the first seven countries in the world with the abundance of geothermal resources, but has only used about 7% of its potential (Mertoglu et al., 2010). It is estimated that geothermal heating potential of Turkey corresponds to 5 million residence equivalent and 48 million ton/year CO_2 emission reduction. As a result, releases of 48 million ton/year CO_2 emissions into the atmosphere will be prevented. Therefore, it is expected that geothermal energy development will dramatically speed up in the future (Kömürcü and Akpınar, 2009). The need to control atmospheric emissions of greenhouse and other gases and substances will increasingly have to focus on efficiency in energy production, transmission, distribution, and consumption in the country. On the other hand, electricity supply infrastructure in Turkey, as in many developing countries, is rapidly expanding, as policymakers and investors around the world increasingly recognize electricity's pivotal role in improving living standards and sustaining economic growth (Utlu and Hepbasli, 2007).

Exergy analysis is a very useful method, which can be successfully utilized in the design of an energy system and provides useful information to choose the appropriate component design and operation procedure. This information is much more effective in determining the plant and operation cost, energy conservation, fuel versatility, and pollution (Kuzgunkaya, and Hepbasli, 2007). Bejan (1982) pointed out that the minimization of lost work in the system would provide the most efficient system. Moreover, Bejan (1988) and Szargut et al. (1988) emphasized that the effect of operating conditions on the system efficiency was much stronger for lost-work analysis than it is for the heat balance analysis. This explanation is required to determine the inefficient process, equipment, or operating procedure during the process. In recent years, exergy analysis has been widely used for the performance evaluation of thermal systems. By using exergy analysis method, magnitudes and locations of exergy destructions (irreversibilities) in the whole system are identified, while potential for energy efficiency improvements is introduced. With the same way, exergy efficiency, specific exergy index, and sustainability index will be much more important to determine geothermal sources efficiency.

In this paper, brief information has been given about geothermal potential of Turkey and geothermal energy usage of Turkey because of emphasis on the geothermal potential of Turkey. In this study, using specific exergy index analysis methods, some of Turkey's geothermal energy sources were investigated from the point of exergy. Exergy efficiency data collected from literature on several geothermal plants was used to calculate the sustainability index. Then, the efficiency in the use of geothermal resources was examined. The aim of this exergy analysis of Turkey's geothermal energy sources is to show Turkey's geothermal capability with special attention drawn to country's geothermal energy use efficiency.

2. GEOTHERMAL ENERGY UTILIZATION IN TURKEY

Turkey, which is located on the Alpine-Himalayan orogenic belt, has high geothermal potential. The first geothermal research and investigations in Turkey were started by the General Directorate of Mineral Research and Exploitation (MTA) in the 1960s. Since then, 190 geothermal fields have been discovered by MTA, 95% of which are low to medium enthalpy fields that are mostly suitable for direct-use applications. Around 1500 hot and mineralized natural springs and wells with temperatures ranging from 20 to 287.5°C exist in Turkey. With the existing geothermal wells and spring discharge water, the proven geothermal capacity calculated by the MTA is totally 4500 MWt (megawatt thermal) (exhaust temperature is assumed to be 35°C). The total geothermal potential is estimated as 31,500 MWt (5,000,000 residences equivalent). This figure also means that 30% of the total residences in Turkey could be heated by geothermal energy. Most of the development has been achieved in geothermal direct-use applications by 201,000 residences equivalent geothermal heating (1494 MWt) including district heating, thermal facilities, and 2,300,000 m^2 geothermal greenhouse heating. A total of 260 spas are used in Turkey for balneological purposes (552 MWt) (Mertoglu et al., 2010; Çapik et al., 2012; MTA, 2014).

In Turkey, geothermal energy is mainly used in thermal tourism, heating applications, greenhouse heating, industrial mineral (liquid CO_2), and in electricity production. In Turkey, there are 18 geothermal fields discovered by MTA, which are suitable for geothermal power production. Within these, 11 fields are currently being used for electricity production and/or in project stage with license. Some of the electricity production fields and installed capacities include Denizli/Kızıldere (15 MWe), Aydın/Germencik, (47.4 MWe), Çanakkale/Tuzla (7.5 MWe), Aydın/Salavatlı (7.95 MWe and 9.5 MWe), and Aydın-Hıdırbeyli (20 MWe) and total constructed electricity capacity is 243.35 MWe. As seen in Figure 1, development of geothermal power production progressed slowly between 1985–2005 years, and spurted since then (Baba, 2010; Mertoğlu ve Başarır, 2013).

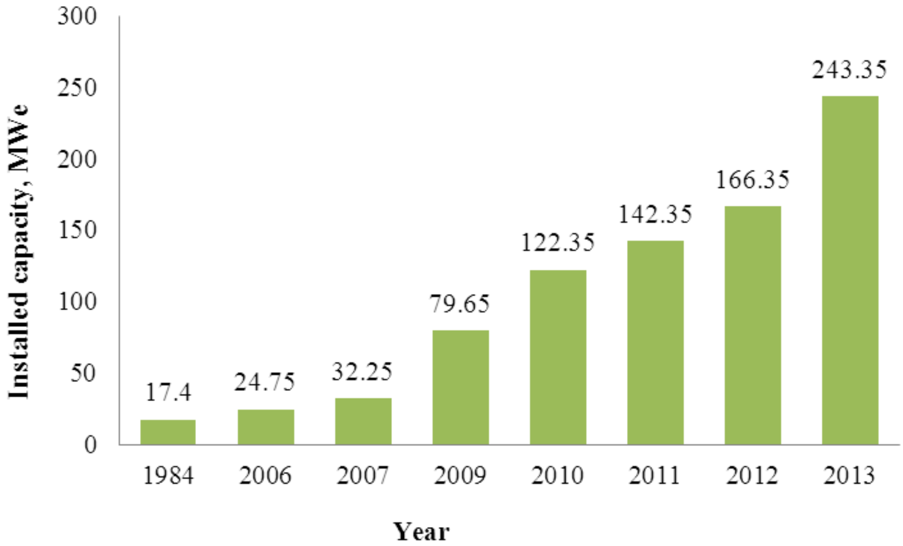

Figure 1: Electricity production from geothermal energy in Turkey.

In Turkey, the direct-use applications from geothermal energy include district heating, greenhouse heating, and thermal tourism facilities and Figure 2 shows the percentage distribution of geothermal energy direct-use. Currently, geothermal district heating capacity is 805 MWt, 89443 residence equivalent. Greenhouse heating is applied to about 3 million m^2 (612 MWt) and there are over 350 thermal resorts which offer balneologic treatment and thermal tourism applications (870 MWt) (Mertoğlu ve Başarır, 2013).

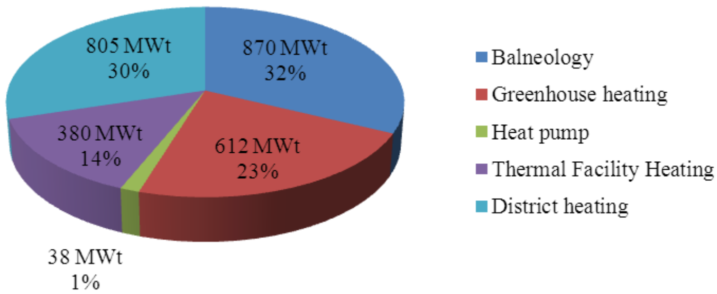

Figure 2: Percentage distribution of geothermal energy direct-use.

By summing up all these geothermal utilizations, the installed capacity is 2705 MWt for direct-use (including heat pump applications totally 38 MWt) and 243.35 MWe (megawatt electrical) for power production in Turkey, where a liquid carbon dioxide and dry ice production factory is integrated into this power plant. About 7% of our total geothermal potential has been utilized so far. 550 MWe power productions and 4000 MWt space heating is planned to be achieved in 2015. With the huge thermal tourism capacity potential of Turkey, the target is to increase the numbers of local curists (tourists in thermalism) to 15 million people and the foreign curists to 250,000 by the year 2015.

3. EXERGY

Exergy is a measure of the maximum capacity of a body or an energy system to perform the useful work, as it proceeds to a specified final equilibrium state with its surroundings. The surroundings of an energy source can strongly affect the availability of work. The amount of the available work will be higher when there is a large difference between the energy source and its surroundings. The convertible energy of a system is proportional to the difference between an energy source and its surroundings. Therefore, energy and exergy do not stand for the same meaning (Saidur et al., 2007a). Exergy can also identify better than energy the environmental benefits and economics of energy technologies. The results suggest that exergy should be utilized by engineers and scientists, as well as decision and policy makers that are involved in green energy and technologies in tandem with other objectives and constraints (Rosen et al., 2008).

Exergy analysis method is employed to detect and to quantitatively evaluate the causes of the thermodynamic imperfection of the process under consideration (Rosen and Dincer, 2003). The exergy consumption during a process is proportional to the entropy created due to irreversibilities associated with the process (Korones et al., 2011).

Dincer (2002) reported the linkages between energy and exergy, exergy and the environment, energy and sustainable development, and energy policy making and exergy in detail. He suggested the following key points to highlight the importance of the exergy and its essential utilization in numerous ways: (a) it is the primary way in best addressing the impact of energy resource utilization on the environment, (b) it is an effective method using the conservation of mass and conservation of energy principles together with the second-law of thermodynamics for the design and analysis of energy systems, (c) it is a suitable technique for furthering the goal of more efficient energy-resource use, as it enables the locations, types, and true magnitudes of wastes and losses to be determined, (d) it is an efficient technique revealing whether it is possible or not, and providing it is possible, then how much it is possible to design more efficient energy systems by reducing the inefficiencies in existing systems, and (e) it is a key component in obtaining a sustainable development.

Considering the discussions and literature mentioned above, it is obvious that analysis of exergy is crucial for energy planning, resource optimization, and global environmental, regional, and national pollution reduction (Saidur et al., 2007b).

3.1 General Relations

The mass balance equation can be expressed in the rate form as

$$\sum \dot{m}_{in} = \sum \dot{m}_{out} \tag{1}$$

where $\dot{m}$ is the mass flow rate, and the subscript in stands for inlet and out for outlet.

The general energy balance can be expressed below as the total energy inputs equal to total energy outputs.

$$\Sigma \dot{E}_{in} = \Sigma \dot{E}_{out} \tag{2}$$

The general exergy balance can be written as follows:

$$\Sigma \dot{Ex}_{in} - \Sigma \dot{Ex}_{out} = \Sigma \dot{Ex}_{dest} \tag{3a}$$

or

$$\dot{Ex}_{heat} - \dot{Ex}_{\text{work}} + \dot{Ex}_{mass,in} - \dot{Ex}_{\text{mass,out}} = \dot{Ex}_{dest} \tag{3b}$$

with

$$\dot{Ex}_{heat} = \Sigma(1 - \frac{T_0}{T_k})\dot{Q}_k \tag{4a}$$

$$\dot{Ex}_{work} = \dot{W} \tag{4b}$$

$$\dot{Ex}_{mass,in} = \Sigma \dot{m}_{out}\psi_{out} \tag{4c}$$

$$\dot{Ex}_{mass,out} = \Sigma \dot{m}_{out}\psi_{out} \tag{4d}$$

where $\dot{Q}_k$ is the heat transfer rate through the boundary at temperature T_k at location k and $\dot{W}$ is the work rate.

The flow (specific) exergy is calculated as follows:

$$\psi = (h - h_0) - T_0(s - s_0) \tag{5}$$

where h is enthalpy, s is entropy, and the subscript zero indicates properties at the restricted dead state of P_0 and T_0.

The rate form of the entropy balance can be expressed as

$$\dot{S}_{in} - \dot{S}_{out} + \dot{S}_{gen} = 0 \tag{6a}$$

where the rates of entropy transfer by heat transferred at a rate of $\dot{Q}_k$ and mass flowing at a rate of $\dot{m}$ are $\dot{S}_{heat} = \frac{\dot{Q}_k}{T_k}$ and $\dot{S}_{mass} = \dot{m}s$, respectively.

Taking the positive direction of heat transfer to be to the system, the rate form of the general entropy relation given in Eq. (6a) can be rearranged to give

$$\dot{S}_{gen} = \sum \dot{m}_{out} s_{out} - \sum \dot{m}_{in} s_{in} - \sum \frac{\dot{Q}_k}{T_k} \tag{6b}$$

Also, it is usually more convenient to determine $\dot{S}_{gen}$ first and then to evaluate the exergy destroyed or the irreversibility rate $\dot{I}$ directly from the following equation, which is called the Gouy-Stodola relation (Szargut, 2005):

$$\dot{I} = \dot{E}x_{dest} = T_0 \dot{S}_{gen} \tag{7}$$

3.1.1 Energy and exergy efficiencies

Numerous ways of formulating exergetic (or exergy or second-law) efficiency (effectiveness, or rational efficiency) for various energy systems are given in detail elsewhere (Cornelissen, 1997). It is very useful to define efficiencies based on exergy (also called the Second Law of efficiency). Although there is no standard set of definitions in the literature, two different approaches are generally used - one is called "brute-force", whereas the other is called "functional" (DiPippo, 2004).

• A "brute-force" exergy efficiency for any system is defined as the ratio of the sum of all output exergy terms to the sum of all input exergy terms.

• A "functional" exergy efficiency for any system is defined as the ratio of the exergy associated with the desired energy output to the exergy associated with the energy expended to achieve the desired output.

Here, in a similar way, exergy efficiency is defined as the ratio of total exergy output to total exergy input, i.e.

$$\varepsilon = \frac{\dot{E}x_{output}}{\dot{E}x_{input}} = 1 - \frac{\dot{E}x_{dest}}{\dot{E}x_{input}} \tag{8}$$

where "output or out" stands for "net output", "product", "desired value" or "benefit", and "input or in" stands for "given", "used" or "fuel".

It is clear that the brute-force definition can be applied in a straightforward manner, irrespective of the nature of the component, once all exergy flows have been determined. The functional definition, however, requires judgment and a clear understanding of the purpose of the system under consideration before the working equation for the efficiency can be formulated (DiPippo, 2004).

3.2 Specific Exergy Index

Geothermal resources have been classified as low, intermediate, or high enthalpy resources according to their reservoir temperatures. The temperature ranges used for these classifications are arbitrary and they are not generally agreed upon. Temperature is used as the classification parameter because it is the earliest to measure and understand. However, the temperature alone is not a good classification parameter. For example, two geothermal resources can both have a temperature of 200 ºC, but one can be saturated water and the other saturated steam. In fact, the specific exergy of the steam is five times higher than that of the water. Like temperature, it is alone inappropriate to define or classify the geothermal resources by enthalpy alone. The lower enthalpy fluid is classified as a high enthalpy resource by its temperature and the higher enthalpy one as an intermediate resource according to its temperature. In fact, it is difficult to tell which one is a better 'quality' resource with only one of the "p", "T" and "h" information in hand. However, it can be easily shown that the lower temperature and high enthalpy fluid is nearly three times exergetically better than the other (Lee, 2001).

Specific exergy values vary on saturated line from 0 to 1192 kJ/kg for saturated steam at 90 bar absolute (9MPa) with triple point condition. Specific exergy values alone do not appear to be a good parameter for the classification of geothermal resources, although we can draw arbitrary lines at, say, exergies over 600 kJ/kg for high exergy resources and exergies below 60 kJ/kg for low exergy resources. The normalized exergy values, henceforth referred to as SExI for 'specific exergy index', vary between 0 and 1 for saturated steam and water and its equation is shown in the following Equation 9 (Lee, 2001).

$$SExI = \frac{h_{brine} - 273.16 s_{brine}}{1192} \tag{9}$$

The equation for SExI is a straight line on an h-s plot of the Mollier diagram. Straight lines of SExI = 0.5 and SExI = 0.05 can, therefore, be drawn in this diagram and used as a map for classifying geothermal resources (Fig. 3).

- SExI < 0.05 for low-quality geothermal resources,

- 0.05 ≤ SExI < 0.5 for medium-quality geothermal resources, and

- SExI ≥ 0.5 for high-quality geothermal resources.

In order to map any geothermal field on the Mollier diagram as well as to determine the energy and exergy values of the geothermal brine, the average values for the enthalpy and entropy are then calculated from the following equations:

$$h_{brine} = \frac{\sum_{i}^{n} \dot{m}_{w,i} h_{w,i}}{\sum_{i}^{n} \dot{m}_{w,i}} \qquad (10)$$

$$s_{brine} = \frac{\sum_{i}^{n} \dot{m}_{w,i} s_{w,i}}{\sum_{i}^{n} \dot{m}_{w,i}} \qquad (11)$$

Hence, by plotting the enthalpy and entropy of a resource's fluid on the map, the category of the geothermal resource can immediately be identified. The thermodynamic properties of water are taken from Cengel and Boles (1996).

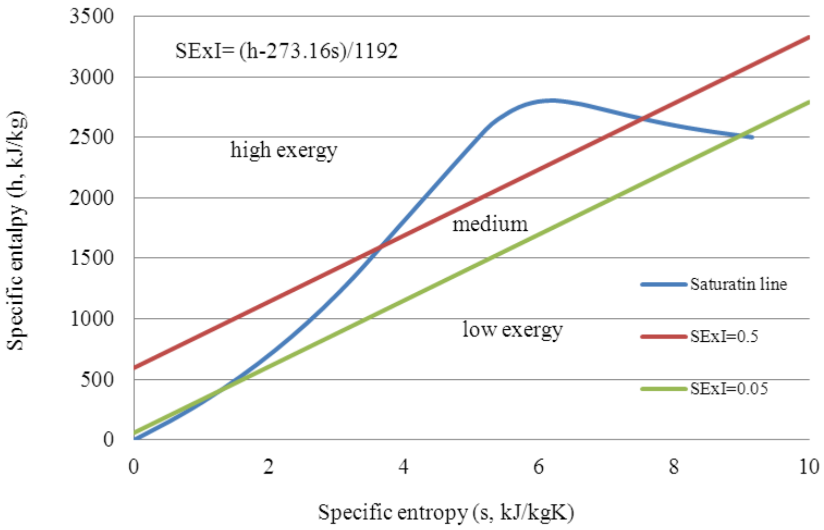

Figure 3: Map for classification of geothermal resources by SExI on Mollier diagram

3.3 Sustainability index

The sustainable supply of clean and affordable energy resources as well as the efficient usage of these are vital for sustainable development. Exergy analysis has a big potential to improve efficiency by maximizing the benefits and by efficient use of resources as well as by minimizing the detrimental effects such as environmental damages. Therefore, the exergy analysis can be applied to amend the efficiency and sustainability of the thermal systems. The relation between exergy efficiency and the sustainability index can be expressed as follows (Gungor et al., 2011):

$$\varepsilon = 1 - \frac{1}{SI} \qquad (12)$$

where, SI is the sustainability index.

4. Results and Discussion

There are a number of studies about exergy analysis of geothermal plants in Turkey. Some of these are listed based on their temperature, power, energetic features and exergetic efficiency and reference in Table 1.

Ganjehsarabi et al. (2012) studied the exergy analysis of the Dora II geothermal power plant (DGPP) with a net power output of 9.5 MW. They found that the exergy destructions/losses take place through losses in the vaporizer, preheater, turbines, pumps, and cooling tower, and through the re-injection of the geothermal fluid. The exergy destruction ratios for these units and processes account for 7.97%, 1.25%, 11.93%, 1.3%, 14.92%, and 32.18% of the total exergy input to the plant, respectively. Among the observed components in the plant, the most efficient equipment is found to be the preheater with an exergy efficiency value of 98%. The overall energetic and exergetic efficiencies of the plant are calculated to be 10.7% and 29.6%, respectively.

A modified exergoeconomic model is studied by Coskun et al. (2011). The Tuzla geothermal power plant system has a total installed capacity of 7.5 MW and was recently put into operation. Electricity is generated using a binary cycle. Exergy efficiency values vary between 35% and 49% with an average exergy efficiency of 45.2%.

The heat source of the Afyon geothermal district heating system (AGDHS) originates from the Omer/Gecek geothermal field, 15 km northwest of the city of Afyon. An average reservoir temperature of wells in this field is 105°C. The AGDHS was initially designed for 10,000 residences equivalent but today, 4159 residences, covering a total floor-area of 513,683 m^2, are heated. Potential of the AGDHS is 48.333 MWt. The energy and exergy efficiencies of the AGDHS are found to be 37.59% and 47.54%, respectively. The largest exergy destruction occurred in the heat exchangers with 14.59% and then in the reinjection wells with 14.09%. In the AGDHS, the energy recovery should be implemented and can be improved with more efficient heat exchangers and more effective reinjection wells. Based on the four production wells, the specific exergy index (SExI) is found as 0.049. This indicates that the Omer-Gecek geothermal field falls into the low-quality geothermal resource according to Lee's classification (Keçebas, 2011).

The Salihli geothermal field has a maximum yield of 0.087 m^3/s at an average reservoir temperature of 95°C and a minimum capacity of 838 MW. The Salihli geothermal district heating system (SGDHS) was initially designed with a capacity to serve the equivalent of 20,000 residences. As of February 2004, 2400 residences were heated by geothermal energy. The energy and exergy efficiencies of the SGDHS are determined as 55.5% and 59.4%, respectively. The greatest exergy loss of 20.44% is caused by the natural direct discharge of the system due to a significant amount of water leaks and includes some of the exergy destruction through the primary and secondary fluid networks. The second largest exergy destruction (17.90% of the total exergy input, or about 459 kW) occurs in the heat exchangers. This is followed by the total exergy destruction associated with the pumps, which amounts to 57 kW or 2.22% of the total exergy input to the system (Ozgener et al., 2007).

In the Balcova geothermal district heating system (BGDHS), the exergy losses are observed to have occurred mainly due to the losses in pumps, heat exchangers, and reinjection sections of the geothermal water back into the reservoir and pipeline, and account for 1.75%, 8.84%, 14.20%, and 28.69%, respectively. Energy and exergy efficiencies of the system are found as 42.36% and 46.55%, respectively, on the 2nd January 2004 (Ozgener et al., 2006).

Oktay et al. (2008) performed the performance analysis of the Bigadic Geothermal District Heating System in Balikesir, Turkey. The overall energy and exergy efficiencies of the system for two reference temperatures were taken as 15.6 8˚C for November (e.g., case 1) and 11.8˚C for December (e.g., case 2). The average energy and exergy efficiencies are found as 30% and 36% for case 1, and 40% and 49% for case 2, respectively. The key reason as to why the exergy efficiencies are higher is because the heat recovery option is used through the reinjection processes, which make use of waste heat.

The first geothermal district heating system was installed in the Gonen field (in Balikesir) in 1987, and by 1990 it was heating 600 residences. Between 1990 and 1995 direct uses of geothermal energy increased by as much as 185%. The results of research work in the Gonen geothermal district heating system (GGDHS) indicate that the exergy destructions in the system occur primarily as a result of losses in the pumps, heat exchangers, and pipelines, as well as losses associated with cooled geothermal waters injected back into the reservoir. These losses amount to 14.81%, 7.11%, 1.06%, and 12.96% of the total exergy input to the GGDHS, respectively. Both energy and exergy efficiencies of the overall GGDHS were investigated to analyze and improve the system performance. The efficiencies were determined as 45.91% and 64.06%, respectively (Ozgener et al., 2005).

The present wells located in the Simav geothermal field are used for district heating, greenhouse heating, and balneological purposes. Simav geothermal district heating system (SiGDHS) has started operation in October 1991 by heating 3200 residences. To date, 5000 residences have been heated using geothermal fluid. Simav is one of the most important 15 geothermal areas in Turkey. It has several geothermal resources with the mass flow rate ranging from 35 to 72 kg/s and temperature from 88 to 148.8˚C. Hence, these geothermal resources are available to use for several purposes, such as electricity generation, district heating, greenhouse heating, and balneological purposes. A greenhouse area of 225,000 m^2 is also heated by geothermal. SiGDHS has an energetic efficiency of 26.30% and an exergetic efficiency of 37.41% which are relatively lower in comparison with the other geothermal district heating systems in Turkey. In this case, entropy generation, which is the primary cause of the global warming problem for such systems, is about 4.06 kW (Arslan et al., 2009).

Recent technical developments have made it possible to generate electricity from geothermal resources with low and medium enthalpy. One of these technologies is the Kalina Cycle System (KCS-34). Electricity generation from Simav geothermal field operative with KCS-34 is investigated by Arslan (2010). The optimum operating conditions for the KCS-34 plant design were determined on the basis of the exergetic and life-cycle-cost concepts. With the best design, power generation of 41.2 MW and electricity production of 346.1 GWh/a can be obtained with an energetic efficiency of 14.9% and exergetic efficiency of 36.2%.

Table 1: Exergy analysis results of completed investment of some geothermal field in Turkey

Location	Type	Year	Power (Mwe, MWt)	Temperature (°C)	Energetic efficiency (%)	Exergetic efficiency (%)	Reference
Aydın/Salavatlı-Dora II	GPP	2010	9.50	171	10.7	29.6	Ganjehsarabi et al., 2012
Çanakkale/Tuzla	GPP	2011	41036.00			45.2	Coskun et al., 2011
Kutahya/Simav	GPP		41.2	148	14,90	36.2	Arslan, 2010
Afyon	GDHS	1994	48.333	105	37.59	47.54	Keçebas, 2011
Manisa/Salihli	GDHS	2004	838		55.5	59.4	Ozgener et al., 2007
İzmir/Balçova	GDHS	2001	82.67-104.75	95 - 140	42.36	46.55	Ozgener et al., 2006
Balıkesir /Bigadiç	GDHS	2006	15.253	110	30-40	36-49	Oktay et al., 2008
Balıkesir/Gönen	GDHS	1987		70	45.91	64.06	Ozgener et al., 2005
Kutahya/Simav	GDHS	1991		98	26.30	37.41	Arslan, et al., 2009

Specific Exergy Index of geothermal resources in Turkey was studied. A specific enthalpy-specific entropy (h–s) diagram used for classification of some Turkish geothermal resources is shown in Fig. 4. Geothermal fields at Kızıldere are plotted on the classification map in Figure 4 using the data from Gokcen et al. (2004). The thermodynamic properties of the Germencik field are based on the data collected in June 2011. Data from the Balçova (Baba et al., 2006), Gönen (Ozgener et al., 2005), Simav (Kose, 2007; Arslan, 2010), Salavatlı (Durmuş, 2006; Ganjehsarabi et al., 2012) and Afyon (Keçebas, 2011) fields are also included.

As shown in Figure 4, hot water resources at atmospheric pressure have SExI=0.05 including the Afyon, Gönen, Balçova, Salihli, Bigadiç and Simav fields, all of which are low exergy resources. These areas are more appropriate for direct heating and these areas are currently being used for thermal tourism, direct heating, and greenhouse applications. In fact, these areas have already been used for geothermal district heating system (Table 2). SExI values of the Germencik, Kızıldere, Salavatlı, and Simav areas are calculated as over 0.5 and they plot within the high exergy zone of the diagrams. Also indicated in Figure 4 is that these areas are used for electricity production and are convenient for electricity production.

In consideration of calculations made, the geothermal potential of Turkey is quite good and if it is evaluated, it will make a significant contribution to country's economy.

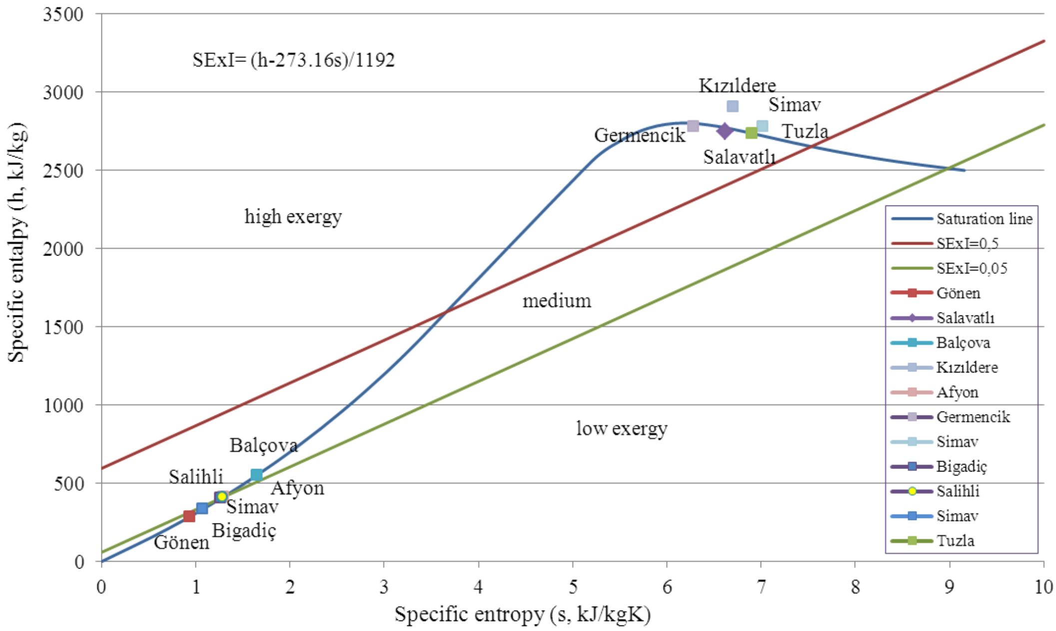

Figure 4: Examples of geothermal fields plotted on the classification map of geothermal resources.

In this study, sustainability index for each instruction was calculated using Equation 12 and calculated values are provided in Table 2. As shown in Table 2, the highest SI value was found in Balıkesir/Gonen with 2.782 and the lowest SI value was found in Aydın/Salavatlı-Dora II with 1.420. SI values calculated are 2.463 for Manisa/Salihli, 1.906 for Afyon, 1.871 for İzmir/Balçova, 1.825 for Çanakkale/Tuzla, 1.739 for Balıkesir /Bigadiç, 1.598 for Kutahya/Simav, and 1.567 for Kutahya/Simav.

In the evaluation of resources (SExI) and plant (SI), while Dora II in GPP has a good SExI value (0.790), it has the lowest exergy efficiency (0.30) and SI value (1.420). Improvements for Dora II are therefore required. Balıkesir, with the lowest SExI value (0.026) in resources, has drawn attention as it has the highest SI value (2.782). Izmir/Balçova's SExI value is higher than the other ground direct heating systems. But its SI value is quite low when compared to other areas such as Manisa/Salihli GDHS.

Table 2: Evaluation with exergy index of completed investment of some geothermal fields in Turkey

Location	Type	Energetic efficiency	Exergetic efficiency	SExI	SI
Aydın/Salavatlı-Dora II	GPP	0.11	0.30	0.790	1.420
Kutahya/Simav	GPP	0.15	0.36	0.725	1.567
Çanakkale/Tuzla	GPP	0.00	0.45	0.714	1.825
İzmir/Balçova	GDHS	0.42	0.47	0.086	1.871
Afyon	GDHS	0.38	0.48	0.051	1.906
Manisa/Salihli	GDHS	0.56	0.59	0.050	2.463
Balıkesir /Bigadiç	GDHS	0.35	0.43	0.049	1.739
Kutahya/Simav	GDHS	0.26	0.37	0.035	1.598
Balıkesir/Gönen	GDHS	0.46	0.64	0.026	2.782

6. Conclusions

The use of sustainable energy not only provides sufficient energy for the present and future energy needs, but also protects the environment and the integrity of ecosystems. In addition, it provides measures to avoid security threats and potential geopolitical conflicts that might occur from increasing competition for the improperly scheduled distribution of energy resources (IEA, 2008).

The main conclusions derived from the present study can be summarized as follows:

- The present use of geothermal energy is a very small fraction of the identified geothermal potential. Only 7% of the geothermal source potential of Turkey has been used so far. When Turkey utilizes all of its total geothermal potential, it can meet 12.7% of its total energy needs.
- As can be seen from the SEIx analysis, geothermal resources in Turkey are appropriate for use as a geothermal plant and direct-use.
- It may be 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, emission of 48 million ton/year CO_2 into the atmosphere can be prevented.
- For the governments or societies to attain sustainable development, much effort should be devoted to utilizing sustainable and renewable energy resources.
- The results suggest that exergy should be utilized by engineers and scientists, as well as decision and policy makers, involved in green energy and technologies in tandem with other objectives and constraints.
- Exergy clearly identifies efficiency improvements and reductions in thermodynamic losses attributable to green technologies.
- Thus, exergy has an important role in increasing utilization of green energy and technologies.

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