

**Research Article**

Thermodynamic performance analysis of geothermal and solar energy assisted power generation and residential cooling system

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ARTICLE INFO

Article history:

Received 08 January 2020

Revised 06 March 2020

Accepted 09 March 2020

Keywords:

Absorption refrigeration

Geothermal energy

Solar energy

ABSTRACT

In this study, geothermal and solar assisted cogeneration system is modeled to the supply of electricity and cooling. The energy requirements of Afyon Kocatepe University, Faculty of Technology building, are investigated. The building cooling system is performed by using heat energy provided from geothermal and solar energy in an absorption cooling system. Subsequently, it is aimed to generate electricity in the Organic Rankine Cycle (ORC) with geothermal water and waste heat leaving the cycle. It is planned that the electricity produced in the power cycle is supplied to the grid system according to the requirement. The cooling load of the faculty building is calculated by considering the working conditions of the faculty building. The ideal thermodynamic analysis and performance evaluation of the system has been performed by using Engineering Equation Solver (EES) software into consideration by considering the cooling season, geothermal and solar energy data of Afyon in the summer season. The parametric study of the system is performed by considering different geothermal water temperature and solar radiation. The reversible COP of the absorption cooling system is calculated to be 3.18. The maximum heat energy value obtained from solar energy is calculated to be 74.97 kW in June. The highest ideal cooling capacity and maximum power provided from geothermal and solar assisted cogeneration energy systems are calculated to be 40,222 kW and 4688 kW, respectively, in June. These results are sufficient to supply the electrical and cooling requirements of the faculty building.

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1. Introduction

In the industrial application, energy is the most important material to solve the problem of requirements. Especially developing countries need too much energy consumption that machines work with consumed in industrial applications. For that reason, this problem should be solved by alternative energy resources. Currently, the most commonly used energy resources are the fossil-based energy sources in the world. These conditions bring with some problems. Some of these are the depletion of fossil fuels, the harmful effect on the environment, and human health. Two methods are used to reduce the harmful effects of fossil fuel emissions. One is to improve the technology of energy conversion systems and fuels better combustion occurs, and fewer emissions are produced. The second method is the alternative energy resources. For instance, this issue has led us to

alternative energy sources, which are renewable and sustainable energies. Today, the best-known alternative energy sources are renewable energy sources in which wind, solar, hydro, geothermal, and biomass are the most common. Produced renewable electricity must be economically competitive level with against fossil-based energy resources [1].

Renewable energies are currently the fastest-growing energy source in the world. Depletion and emission concerns over fossil fuel use and increasing government incentives can cause even higher growth in the use of renewable sources in the coming decades. An energy source is called renewable if it can be renewed and sustained without any depletion and any significant effect on the environment. It is also called alternative, sustainable, or a green energy source. Fossil fuels such as coal, oil, and natural gas, on the other hand, are not

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DOI: 10.35860/iarej.672356

renewable, and they are depleted by use. They also emit harmful pollutants and greenhouse gases. Primary renewable energy sources include solar, wind, hydro, biomass, and geothermal. Energies from the ocean, including wave and tidal energies, are also renewable sources, but they are currently not economical, and the technologies are still in the experimental and developmental stages [2].

The best-known renewable source is solar energy. Although solar energy is sufficient to meet the entire energy needs of the world, currently, it is not used as extensively as fossil fuels because of the low concentration of solar energy on earth and the relatively high capital cost of harnessing it. Another most popular renewable energy source is geothermal energy. Geothermal energy refers to the heat of the earth. High temperature underground geothermal fluid found in some locations is extracted, and the energy of the geothermal fluid is converted to electricity or heat. Geothermal energy conversion is one of the most mature renewable energy technologies. Geothermal energy is mostly used for electricity generation and district heating. Especially Afyon province has great potential in terms of geothermal and solar energy sources. In this study, the potential for efficient use and alternative methods will be investigated [3].

There are many studies in the literature on the use of renewable energy sources such as solar and wind indirect electricity generation or the production of electricity and cooling using geothermal energy. However, studies on the use of geothermal or solar energy in cogeneration energy systems for electricity generation and cooling are limited. In this section, some of the most important of these studies, and some studies about the method to be followed will be mentioned. Zhou et al. [4] of the hybrid solar-geothermal power plant, to increase electricity production and to reduce the effect of daily temperature are researched. For this purpose, they compared the performance of hybrid systems in terms of power output and electricity cost to independent solar and geothermal power plants. As a result of thermodynamic analysis of 120°C source temperature and 50 kg/h geothermal water, they stated that a hybrid plant performs better than a geothermal plant alone. Ezzat et al. [5] have designed a multi-generation energy system supported by geothermal energy and solar energy. In this system, they designed, they aimed to produce electricity, cooling for industry, heating for houses, and hot water for domestic use. They calculated the energy and exergy COP values of the absorption refrigerant and heat pump and the maximum exergy loss in the solar collectors. As a result of their research, they stated that the energy efficiency of the multi-generation energy system is about five times better than the energy efficiency of the basic geothermal

system. Astolfi et al. [6] performed performance and cost analysis of a hybrid solar-geothermal power plant based on the Organic Rankine Cycle (ORC). They performed their research for the regions located in four different cities and estimated the annual net power obtained from the hybrid system with hourly simulation they created in MATLAB program for each region. As a result of their studies, they emphasized that the hybrid solar-geothermal energy system can generate electricity at a lower cost than an independent solar power plant. Yilmaz et al. [7] performed thermodynamic modeling and analysis of the geothermal energy-assisted ammonia-water absorption cooling system. They investigated the coefficient of performance (COP) and exergy efficiency of the modeled system, and they examined the effect of geothermal source temperature change on these important parameters. They calculated the lowest cooling temperature and cooling heat load of the system. Also, they observed how the performance parameters of the system changed with the change of the temperature of the geothermal resource used by performing parametric studies. Yakut et al. [8] investigated to air-condition a meeting room for 30 people in Isparta with an absorption system using LiBr-water as a fluid pair. They calculated the working conditions and cooling loads of the air conditioning system according to months. They calculated the useful temperatures and collector efficiencies obtained in planar solar collectors for each month. As a result of their research, they have reached the number of the solar collector to provide the necessary heat energy. Kuyumcu et al. [9] proposed to cool an apartment using an absorption cooling machine using a single-acting solar-assisted H₂O-LiBr mixture. The cooling energy requirement that they calculate in order to maintain the desired constant indoor temperature in the rooms, they supplied from solar energy through the collectors of absorption the cooling system. They calculated the required collector surface area by considering different types of collectors according to the cooling energy demand of the apartment. Bilgic et al. [10] have performed an artificial neural network using temperature and mass flow data from an experimental Organic Rankine Cycle (ORC). They compared the experimental results and the forecasting results by making power estimation with artificial neural networks (ANN) trained for a 10 kW Organic Rankine Cycle (ORC). As a result of the study, they compared the estimation values obtained from artificial neural networks with the experimental data and calculated the correlation coefficient indicating the performance of the prediction as 0.99124. As a result, they emphasized that power parameters can be calculated by adjusting system parameters according to artificial neural networks. Yagli et al. [11] designed a subcritical and supercritical Organic

Rankine Cycle (ORC) to recover the exhaust gas waste heat of biogas fuelled combined heat and power (CHP) engine. They improved the system parameters as net power, mass flow rate, pump total power consumption, thermal efficiency, and exergy efficiency by changing turbine inlet temperature and pressure. They stated that compared with subcritical ORC, supercritical ORC better performance. Beneta et al. [12] proposed a new combined cooling, heating, and power system (CCHP) driven by solar energy. They worked on a system of Organic Rankine Cycle (ORC) to generate electricity, cooling, and heating, respectively. In their study, they examined the effects of some critical thermodynamic parameters on the performance of the cycle. Yilmaz [13] designed a system to produce clean hydrogen, power, heating, cooling, and freshwater as a multigenerational purpose. Its system consisted of a solar heliostat, a Brayton cycle driven by solar energy, a Rankine cycle, an Organic Rankine Cycle, an absorption cooling and heating system, a flash desalting unit, and a PEM electrolyzer. In his study carried out parametric studies to investigate the effects of different parameters such as turbine inlet pressure, solar radiation, an isentropic efficiency of the compressor, and reference temperature on system efficiency. Zhao et al. [14] worked on a system driven by solar energy consisting of an Organic Rankine Cycle (ORC) and a parabolic trough collector to generate power, cooling, and heating. In their work, they conducted a comprehensive analysis of the influence of configurations of solar-driven ORC based CCHP systems. They stated that, under reasonable thermodynamic boundary conditions, optimal operational

parameters were obtained with ORC 200 kW.

In this study, modeling geothermal and solar assisted cogeneration systems to supply the electricity and cooling requirements of buildings is investigated. Residential cooling is performed by using heat provided from geothermal and solar energy in an absorption cooling system. Subsequently, it is provided to generate electricity in the Organic Rankine Cycle (ORC) with geothermal water and waste heat leaving the cycle. It is objected that the electricity produced in the power cycle is supplied to the grid according to the requirement. The cogeneration system can be supplied to the cooling and electricity requirements of the buildings.

2. Material and Method

2.1 Description of System

In this study, geothermal and solar energy assisted cogeneration energy system has been modeled to supply the electricity and cooling requirements of Afyon Kocatepe University, Faculty of Technology building with 1000 m² area. The overview of the multi-power generation plant system is given in Fig. 1.

The working principle of the system modeled to supply the electricity and cooling requirements of the faculty building is as follows; beneficial heat energy provided from geothermal and solar energy by using in the absorption cooling cycle has cooled the building. Geothermal fluid and waste heat energy leaving the cycle is used to generate electricity in the Organic Rankine Cycle (ORC). The electricity generated in the power cycle is supplied to the grid according to the requirement.

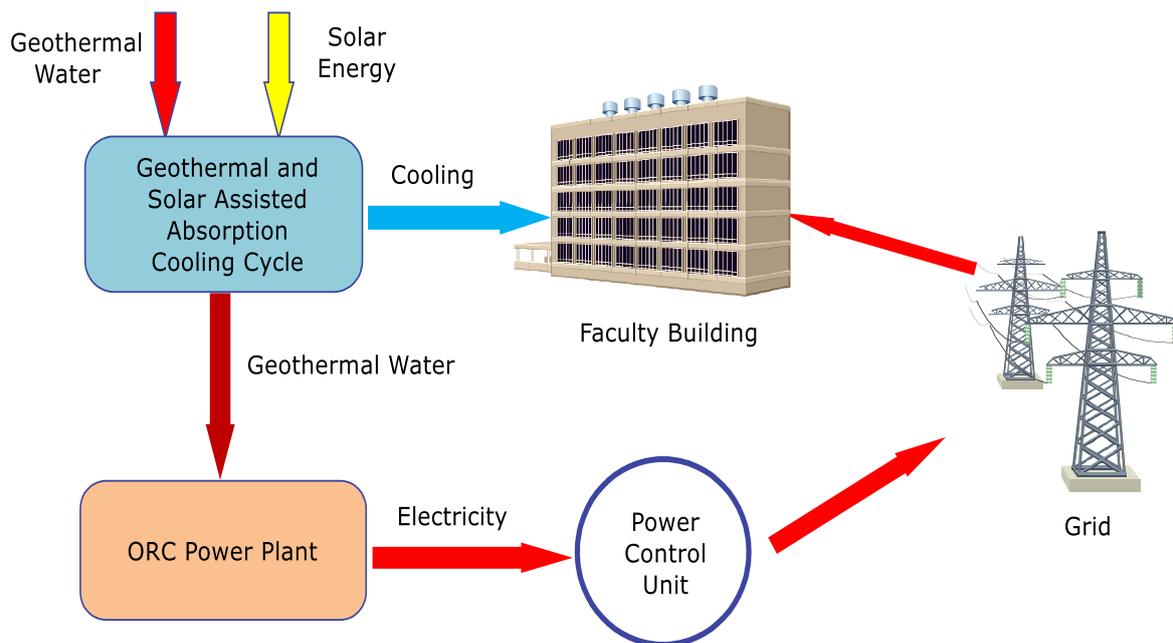


Figure 1. Geothermal and solar energy assisted cogeneration system

2.2 Modeling of System

The geothermal and solar energy assisted cogeneration energy system is modeled in this section. The cooling load of a building represents the heat that must be removed from the interior of a building to maintain it at the desired conditions. The cooling load is determined with a steady-state analysis using the design conditions for the indoors and the outdoors to size the cooling system [15]. In order to supply the total cooling load demanded the building, firstly, the ideal cooling capacity of a single geothermal energy-assisted absorption cooling cycle is calculated. In the geothermal and solar energy assisted absorption cooling cycle, geothermal water enters the cycle at 110°C at a rate of 150 kg/s and leaves the cycle at 90°C.

A flat-plate solar collector is considered for solar energy, the other primary source of the system. The objective of a flat-plate solar collector is to produce useful heat from solar energy. The flat-plate solar collector consists of glazing, an absorber plate, flow tubes, insulation, glazing frame, and a box enclosure. The efficiency of the flat plate solar collector is supposed as %60 [16]. For June, July, and August, where the space cooling is planned, the amount of solar radiation and the required collector surface areas are calculated, and the thermal energies generated by the solar energy are obtained. With the addition of the amount of thermal energy supplied from the solar energy, the ideal cooling loads of the cogeneration energy system are calculated in the summer months. When solar energy is included in the system, changes in the ideal cooling capacities of the cogeneration system are examined. The Organic Rankine Cycle (ORC) is selected for the power plant because the geothermal field of the region has low-temperature scale fields. In the Organic Rankine Cycle, geothermal water enters the cycle at 90°C at a rate of 150 kg/s and leaves the cycle at 70°C. R134a as the working fluid is selected.

2.3 Thermodynamic Analysis of System

In order to maintain the desired ambient temperature constant for each room in the faculty building, the total cooling thermal load of the building must be supplied in summer conditions. Considering the desired design conditions for the rooms, the total cooling thermal load of the building can be determined by the following equation [15].

$$Q_{building} = Q_{room} \times Z + Q_s + Q_{human} + Q_{device} \quad (1)$$

Here Q_{room} is the non-incremental heat gain for the rooms, Z is the combined increment coefficient, Q_s is the air leak heat gain, Q_{human} is the heat gain from humans, and Q_{device} is the heat gain from the devices.

The thermal energy provided from geothermal energy is calculated as follows [16].

$$Q_{geo} = \dot{m}(h_1 - h_2) \quad (2)$$

Where \dot{m} the mass is flow of the geothermal fluid, h_1 and h_2 are the enthalpy values of the inlet and outlet temperatures of the geothermal fluid.

The ideal efficiency coefficient of the geothermal energy assisted absorption cooling system is as follows [16].

$$COP_{abs,rev} = \left(1 - \frac{T_0}{T_S}\right) \left(\frac{T_L}{T_0 - T_L}\right) \quad (3)$$

Here T_0 is the environmental temperature, T_S is the resource temperature and T_L is the desired ambient temperature [16].

$$COP_{abs,rev} = \frac{Q_L}{Q_{geo}} \quad (4)$$

Here Q_L is the ideal cooling capacity of the system.

The maximum work that can be obtained from a liquid geothermal source with a temperature T_S is calculated by the following equation [16].

$$w_{rev,out,geo} = c(T_S - T_0) - T_0 c \ln \left(\frac{T_S}{T_0}\right) \quad (5)$$

The surface area of the collector is calculated as follows [15].

$$A_c = \frac{Q_{required}}{Q_{useful}} \quad (6)$$

Here the useful heat obtained for the unit collector surface area Q_{useful} is the thermal load required for the hot water required $Q_{required}$.

Useful heat is calculated as follows [15].

$$Q_{useful} = H_T \times \eta_{col} \times \eta_m \quad (7)$$

Here H_T is the average monthly solar radiation per collector unit area, η_{col} is collector efficiency and η_m is collector system efficiency.

The required thermal load is determined as follows [15].

$$Q_{required} = \dot{m}c_p(T_w - T_m) \quad (8)$$

Here, \dot{m} is the amount of hot water, c_p is the specific heat of the water, T_w is the desired minimum water temperature, T_m and is the mains water temperature.

The total solar radiation falling on the horizontal surface is calculated as follows [15].

$$I = r_t \times H \quad (9)$$

Here r_t is the ratio of the instantaneous total solar radiation falling on the horizontal surface I to the total daily solar radiation falling on the horizontal surface H . The thermal energy provided from solar energy is calculated as follows [15].

$$Q_{sol} = I \times A_c \tag{10}$$

3. Result and Discussion

In this study, the geothermal and solar assisted cogeneration energy system of a faculty building is investigated by considering geothermal and solar data of Afyon province. The necessary calculations for the electricity and cooling requirements of the building are obtained by using the EES program. The average outside air temperatures of Afyon province for the 3 months planned to cool the faculty building is shown in Table 1. Sunlight intensity of Afyon province for three months is shown in Table 2. In other months, it is considered that the faculty building is not require cooling. As seen in Table 3, the maximum instantaneous solar radiation intensity is calculated as 640.44 W/m² in July.

After the determination of these values, the heat energy values produced by solar energy are obtained. The comparison of the heat energy provided from the solar energy and the total solar radiation values for the 3-month period in which the space cooling is performed is shown in Fig. 2. As shown in Fig. 2, although the maximum instantaneous solar radiation is calculated in July (640.44 W/m²), the heat energy provided from solar energy (71.04 kW) is calculated to be a lower value than the heat energy obtained in other months. The main reason for this situation is that the collector area required in July is less than the other months. In Fig. 3 is shown how a change in the ideal cooling capacity of the system by integrating solar energy into a system operating with

geothermal energy.

As shown in Fig. 3, the addition of solar energy to a system operating with geothermal energy has resulted in a significant increase in the ideal cooling capacity of the system during the summer months. The obtained ideal cooling capacity values indicate that the total amount of energy required for cooling the faculty building (125 kW) can be easily supplied. Fig. 4 shows the ideal cooling capacity and maximum power values provided from the geothermal and solar assisted cogeneration energy system in June, July, and August.

Table 1. Monthly average outside air temperatures in Afyon [17]

Months	Average Outside Air Temperatures (°C)
June	19,0
July	21,9
August	21,5

Table 2. Monthly average sunlight intensity in Afyon [18]

Months	Average Sunlight Intensity (kJ/m ²)
June	23880
July	24271
August	22297

Table 3. Instantaneous solar radiation and required collector fields [18]

Months	Solar Radiation (W/m ²)	Required Collector Field (m ²)
June	630,16	119
July	640,44	111
August	600,58	119

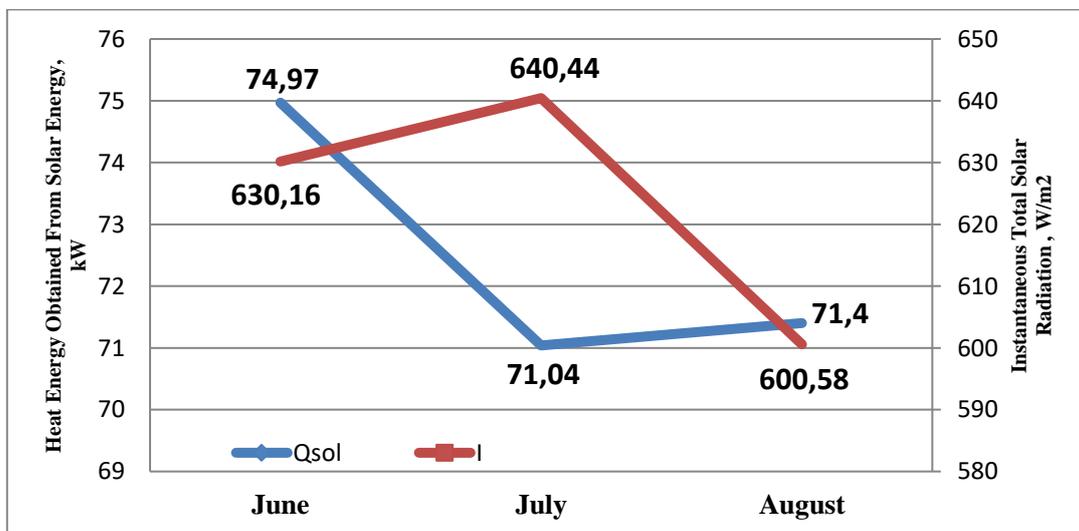


Figure 2. Heat energy provided from solar energy and instantaneous total solar radiation

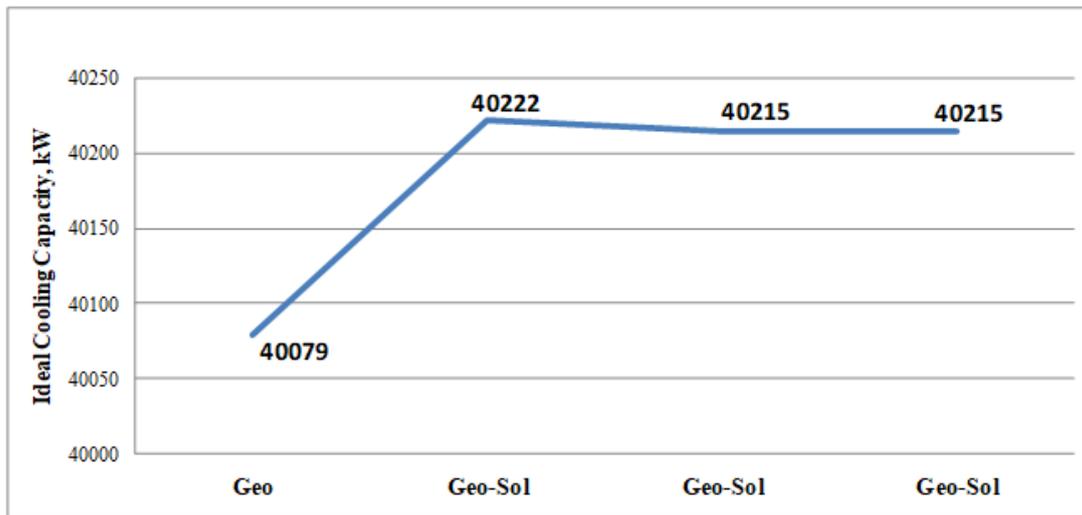


Figure 3. Variation of system ideal cooling capacity

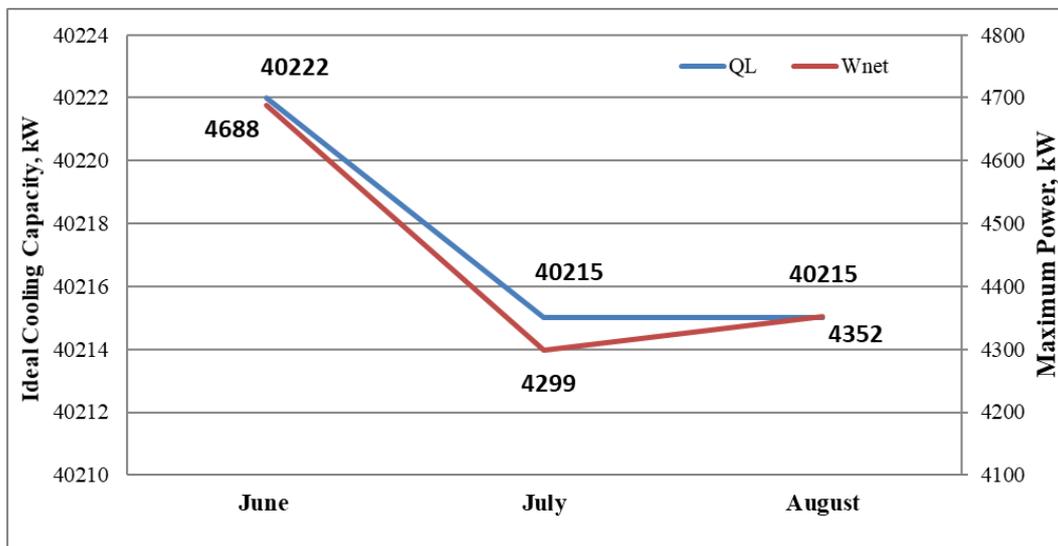


Figure 4. Ideal cooling capacity and maximum power values provided from the system

As shown in Fig. 4, the highest ideal cooling capacity value (40,222 kW) and maximum power value (4688 kW) provided from geothermal and solar assisted cogeneration energy system are calculated in June. These results are sufficient to supply the electrical and cooling requirements of the faculty building.

4. Conclusions

Today, with the gain acceleration of industrialization, energy plays a significant role in the world economy. Sustainable energy production and efficient use of this energy have reached a critical level that will affect the whole world. Therefore, in order to supply the increasing energy demand, the whole world has focused its attention on clean energy. As explained by scientific sources, the damages of fossil fuels to the environment are a valid concern. Geothermal energy,

which is one of the renewable energy sources, is the subject of many kinds of research, and it is one of the sustainable energy sources of the future. In that case, technical and economic problems in energy and heat generation should be solved. There are various methods used in the power generation of these systems, and they require electricity and heat inputs from geothermal sources. In this study, the geothermal and solar energy potential of the Afyon province has been investigated. The region has a productive potential in terms of geothermal energy. Afyon province sunshine duration is higher than the average in Turkey. Although it has a very high potential in terms of solar energy, it is seen that the studies related to the utilization of this energy are not sufficient yet. In Afyon province, the conversion of renewable energy sources to energy the expansion of investments related and the realization of new investments will make a significant contribution to

the energy of the region. The number of companies investing in bioenergy, wind energy, and geothermal energy should be increased.

Declaration

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article. The author(s) also declared that this article is original, was prepared in accordance with international publication and research ethics, and ethical committee permission or any special permission is not required.

Acknowledgment

This work was supported by TUBITAK scope of career development program (project no: 218M739), in Turkey.

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