Int. J. Adv. Eng. Pure Sci. 2021, 33(1): 11-17
DOI: 10.7240/jeps.671234

RESEARCH ARTICLE / ARAŞTIRMA MAKALESİ

A Research on Sustainability of a Geothermal Energy Resource in Kırklareli City

Kırklareli İlinde Jeotermal Enerji Kaynağının Sürdürülebilirliği Üzerine Bir Araştırma

Betül ÖZER[1], Sinem KIZILAY[2]

[1]*Kırklareli University, The Faculty of Technology, Energy Systems Engineering Department, 39000, Kırklareli, Turkey*
[2]*Kırklareli University, Institute of Science, Energy Systems Engineering Programme, 39000, Kırklareli, Turkey*

Abstract
Geothermal energy is one of the most important renewable energy sources which provides a massive contribution to the existing region. Low-enthalpy resources are convenient, especially for direct usage applications such as household and greenhouse heating and thermal tourism with today's technology. Direct usage applications have social and economic positive effects via supplying the primary demand of the local communities, such as heating and nourishment. Although geothermal energy is clean and renewable, that causes adverse environmental impacts during drilling or usage stages. Therefore, some criteria should be taken into consideration for the sustainable evaluation of the source. These criteria can be identified within the determined framework of sustainable development goals for each resource. In this study, a newly discovered geothermal energy resource at Kırklareli- Asılbeyli Region is investigated for potential applications according to the UN (United Nations) Sustainable Development Goals. It is pointed out the precautions should be taken into consideration from the discovery phase until the end of life for sustainable use of the source.
Keywords: sustainable development, geothermal energy, sustainability goals, Kırklareli.

Öz
Jeotermal enerji, yenilenebilir enerji kaynaklarının en önemlilerinden biri olup, bulunduğu bölgeye önemli katkılar sağlamaktadır. Bu kaynağı, konutlarda ve seralarda ısıtma amaçlı olarak veya termal turizm amacıyla doğrudan kullanabilmek için günümüz teknolojisiyle düşük entalpili sahalar yeterli olabilmektedir. Doğrudan kullanım uygulamaları bölge halkının ısınma ve beslenme gibi temel ihtiyaçlarını karşılayarak ekonomik ve sosyal olarak olumlu etkiler yaratmaktadır. Jeotermal enerji temiz ve yenilenebilir olmasına rağmen sondaj esnasında veya kullanım aşamasında çevresel açıdan olumsuz etkilere neden olmaktadır. Bu sebeple enerji kaynağının sürdürülebilir olarak değerlendirilmesi için bazı kriterler dikkate alınmalıdır. Bu kriterler her bir kaynak için belirlenen çerçeve kapsamında sürdürülebilir gelişme hedeflerine uygun olarak belirlenebilir. Bu çalışmada Kırklareli-Asılbeyli Bölgesi'nde yeni bulunan jeotermal enerji kaynağının potansiyel kullanımı BM (Birleşmiş Milletler) Sürdürülebilir Kalkınma Hedeflerine göre incelenmiştir. Kaynağın sürdürülebilir olarak kullanılması için keşfinden kullanım ömrü sonuna kadar gerekli önlemlerin alınması gerektiğine dikkat çekilmiştir.
Anahtar Kelimeler: sürdürülebilir gelişme, jeotermal enerji, sürdürülebilirlik hedefleri, Kırklareli.

I. INTRODUCTION

Energy is the most significant power that shapes the necessities of the world. Increasing population, industrialization, technological improvements lead the world to crisis globally due to finite fossil sources of energy. In order to get a solution to this crisis, fossil energy sources should be replaced by renewable sources gradually. The widespread use of renewable energy sources will be effective in preventing ongoing environmental problems caused by conventional energy sources. According to the Renewables 2018 Global Status Report (REN21) [1], the non-renewable electricity accounts for 73.5% in the global electricity production by the end of 2017. Countries that export petroleum began to search for ways to increase the usage of renewable energy sources for most of their energy needs. Erdil and Erbıyık, and Olabi [2,3] indicated that researches and developments should be achieved the hope of 100% renewable energy by 2050, not only for the developed countries also with the most of the developing countries as well. Moreover, Connolly et al. [4] have claimed 100% renewable energy system in Europe is technically possible by the year 2050 by using the smart energy system approach.

Corresponding Author: Betül ÖZER, Tel: +905427224839, e-posta: betulozer@klu.edu.tr
Submitted: 07.01.2020, **Revised:** 24.10.2020, **Accepted:** 17.11.2020

Since renewable energy sources also have adverse environmental effects, they should be examined under a sustainable development point of view. Sustainable development is defined as providing today's needs without sacrificing the ability of future generations to meet their needs in the Brundtland's report [5]. In this context, sustainable energy can be defined as the energy sources that are expected to be consumed in a time period related to the human generation [6]. The definition indicates the widespread use and utilisation of renewable energy sources in a sustainable manner. Those are the main strategies for energy, environment, and climate change-related issues. On the other hand, energy should be provided by an affordable, accessible, and reliable manner while considering equitable distribution in meeting the economic, social, and environmental needs of the society. Particularly, energy production and consumption should be within the scope of sustainable development terms that lead to efficient use of the resources. The United Nations (UN) set 17 goals for a globally better future, and those are intended to be achieved by the year 2030 [7].

Renewable energy includes solar power, wind, wave, tidal, hydropower, geothermal, biomass, organic waste. Especially, geothermal energy is a type of renewable energy that has been produced commercially for nearly a century, both using directly for heating and transformed into electricity [8]. Geothermal resources are classified as low, medium, and high enthalpy resources by their reservoir temperatures [9]. High enthalpy resources are defined when reservoir temperature is higher than 150ºC, for the temperature 70ºC-150ºC that is called medium enthalpy and low enthalpy resources are called for the temperature 20ºC-70ºC. Medium to high enthalpy resources are used for electricity generation, whereas medium or even low enthalpy sources can be used directly for heating purposes.

Geothermal energy may be utilised in a sustainable manner by means of not damaging the source, which is possible by replacing the energy of the source [10]. Execution of any geothermal project should follow the perspective of sustainable development in order to save the environment for the future, and obtain its ground and underground richness. Direct thermal extraction of the geothermal resource is increased to 25 GWth of total capacity globally, whereas space heating is one of the fastest growing sectors. Particularly, Indonesia and Turkey contributed to the three-fourths of 0.71 GW additional capacity in 2017 by bringing the total global capacity to approximately 12.8 GW. Moreover, Turkey has a grand geothermal energy potential and utilisation ratio, which is listed in the top 5 countries of both power and heat capacity among the US, Indonesia, China, Iceland, Japan, Hungary, with 1.1 GW installed geothermal power by the end of 2017 [1].

Due to execute any sustainable project, an individual framework, which consists of themes and subthemes for the actions to reach sustainability goals is needed. In order to apply the correct framework, The Commission for Sustainable Development (CSD) has called core indicators under these themes and subthemes of the actions to measure and calibrate progress towards sustainable development goals for the development. Accordingly, a sustainable development indicator (SDI) is explained as a "quantitative tool that analyses alterations, while evaluating and communicating progress towards the sustainable use and management of economic, social, institutional and environmental resources" [11]. The indicators also provide an overview of the progress towards a more sustainable economy, society and environment. Furthermore, the indicator framework may be a starting point for decision makers for sustainable energy projects.

Evans et al. [12] stated that environmental footprint has to be taken into account for all planned energy projects, especially for future investments. The environmental footprint expresses the entire lifecycle from reserve mining to processing with emissions, including waste management, particularly reinjection for geothermal projects. In the evaluation of each stage of renewable energy utilisation, the qualification of the impact must be identified with key indicators. The indicators should be based upon environmental, economic and social impacts, resource consumption, waste management, gas emissions, availability of renewable energy sources, and the economic added value, especially to the local economy. Furthermore, Santoyo-Castelazo and Azapagic [13] stated, sustainable energy systems require the consideration of three sustainability dimensions, including environmental, economic, and social impacts. Accordingly, certain indicators under the specified themes should be chosen fitting to the region's characteristic properties for creating a framework to reach the settled sustainability goals. Besides, Shortall et al. [14] defined the sustainability assessment framework, which includes established goals, themes, and indicators that suit geothermal energy projects in Iceland, New Zealand, and Kenya. They determined the goals towards the sustainable geothermal energy, where environmental management was the common goal, and water usage was the most crucial environment-related issue. The study pointed out the fact that sustainable geothermal projects must be analysed locally, and goals must be picked due to region's needs.

Turkey has goals in accordance with sustainable development, like most of the developing countries. According to the 2010-2014 development plan [15], ensuring efficient, effective, safe, and environment-sensitive use of energy from natural resources is a mission for the path of reducing the external energy dependency of Turkey. In this way, the country's welfare will be improved. Correspondingly, sustainability is designed as a framework that covers all energy related themes in the latest strategic plan of

Turkey. All the objectives, targets, and strategies of the plan are based on the principles of environmental, economic, and social sustainability that all make the development of renewable and sustainable energy of Turkey [16]. Furthermore, Turkey has also set a desirous target of supplying 30% of all electricity demand from renewable energy sources in 2023 [17].
Turkey has abundant renewable energy sources of hydropower, biomass, wind, geothermal, and solar energy. Even though all are crucially important to supply energy, they have a dependency on the weather conditions except geothermal energy, which can provide energy all the time of the year [18]. Turkey is located on the Mediterranean portion of the Alpine–Himalayan Tectonic Belt and one of the wealthiest countries in the matter of geothermal resources around the world [19]. Due to this potential, new geothermal reservoirs are being discovered all over Turkey. Likewise, low-enthalpy geothermal resource in Asılbeyli-Kırklareli City at Thrace Region is newly discovered by Mineral Research and Exploration (MTA) [20]. Thrace Region is located on the north-west side of Turkey, including three cities named Tekirdağ, Kırklareli, and Edirne, partially of Istanbul and Çanakkale cities. Çorlu, Çerkezköy, Lüleburgaz, and Keşan are the big towns of the Region, those have a high capacity of industrial zones and takes the significant burden of İstanbul's production, have various exporting factories and provide a variety of goods to all over Turkey. The industrial establishments promote not only the economic growth of the Region but also the population increase, those result raising of energy demand excessively. Accordingly, there are many power plant investments, both existing and planned, including fossil fuels (coal and natural gas) and renewable energy sources (wind, solar, and biomass) in the Thrace Region. One of the newest geothermal energy resources in the Region may be an alternative sustainable renewable energy source option. Geothermal energy is one of the vital renewable and clean energy sources that can provide a massive contribution to the Region via direct or indirect usage for energy supply. That may be a very critical energy resource by providing the return on investment in a relatively short time and relatively less environmental damage.

The operation of geothermal plants should be reliable, and the security of supply should be prioritized. This paper aims to present the sustainable use option of the geothermal energy source in Asılbeyli-Kırklareli location that is one of the significant alternative renewable energy sources in the Thrace Region. In this study, the most related sustainable development goals are examined due to the available data for the geothermal energy source; those are mentioned in the materials and method section.

II. MATERIALS AND METHOD

An individual framework is needed for potential projects to be able to reach the goals, and the framework consists of indicators to point out the levels. Asılbeyli-Kırklareli geothermal energy source was evaluated basing on the related four main goals mentioned by the UN [7]. The data obtained from MTA [21] for the drilled geothermal well were used for the evaluation of the resource potential for sustainability basing on the identified goals. The geothermal reservoir has a depth of 1500 m. According to well test data, the maximum well static temperature is 74.38°C at 1476 meters, and the reservoir level is around 1100-1200 meters according to the water loss test that indicates the temperature is between approximately 55°C and 64°C. The other specifications of the well are given in Table1.

The energy potential of the well is convenient for direct usage applications such as household heating, green housing, and thermal tourism. Direct usage applications can be critical for basic demand, such as the heating and nourishment of the local communities in Kırklareli. The well has 2.38 MWt (MW thermal) energy potential that can be utilised for heating of 340 houses, green housing area of 12,500 m^2, and potential of thermal tourism for approximately 2,600 people [21]. The most related four goals have been identified to specify the sustainability of the geothermal resource through the 17 goals from "The global indicator framework for the Sustainable Development Goals and targets of the 2030 Agenda for Sustainable Development" defined by UN [7]. Since Kırklareli has a significant agricultural production, this geothermal energy source should not cause any water and soil pollution. And this potential's execution should be economically feasible. Therefore, all these criteria had been taken into consideration with compatibility of Kırklareli. The goals selected according to the location-based and geographic conditions are mentioned below:

Goal#1: Clean Energy, that is related to "ensure access to affordable, reliable, sustainable and modern energy for all" (Goal#7) and "make cities and human settlements inclusive, safe, resilient and sustainable (Goal #11), [7] which accounts for the fluid that generated from geothermal reservoirs is replaceable by naturally with groundwater or reinjected from the surface which makes the source sustainable. That is mentioned as the main goal in all the geothermal projects as the source generate clean energy and replenished naturally.

Goal#2: Zero hunger, that is related to "end hunger, achieve food security and improved nutrition, and promote sustainable agriculture" (Goal#2) and UN's Goal #7 [7]. Maximizing the utilisation of geothermal energy is essential and also contributes to sustainability. The production rate should be balanced according to the purpose of the use.

Goal#3: Economic growth and well-being, geothermal power plants, heating and cooling systems should be cost-effective and financially suitable in order to supply benefits to the Region. The project

should carry net positive national and community economic benefits. This goal is related to "promote sustained, inclusive and sustainable economic growth, full and productive employment, and decent work for all" (Goal#8) and "ensure healthy lives and promote well-being for all at all ages" (Goal #3)[7].

Goal#4: Clean water, a geothermal resource, should be utilised causing no adverse environmental effects, and water usage must not interfere with determined beneficial usage of the water resource. This goal is related to "ensure availability and sustainable management of water and sanitation for all" (Goal#6), [7]. Geothermal operations, even from the drilling process, produce gas emissions and wastewater, which may include heavy metals as Arsenic, Mercury, Ammonia, and Boron at various levels. Higher concentrations of heavy metals may cause serious health problems. They also contaminate soil and water sources (both surface and groundwater) used for drinking and agricultural purposes; therefore, reinjection should be applied with comprehensive geothermal resource management, particularly sustainable utilisation of the resource.

Table 1. Chemical analysis lab results of water from geothermal source [21]

Sample Location		**Kırklareli - Asılbeyli**
Temperature and Flow Rate		57 ºC, 30 l/sec (compressor) 3.5 l/sec (artesian)
Smell-Taste		-
Coordinates		E-18 d2 X: 4614580 Y: 0520080
		mg/l
Cations	Na^+	645
	Ca^{++}	4,04
	Mg^{++}	1,74
	NH_4^+	5,3
	Total	656,08
Anions	HCO_3^-	993
	CO_3^{--}	<10
	SO_4^{--}	2,89
	Cl^-	480
	F^-	12
	Br^-	1,5
	NO_3^-	0,64
	PO_4 (total)	<0,1
	Total	1.490,03
Others	SiO_2	25,1
Total Mineralization (mg/l)		2.171,21
pH (26,8 ºC)		7,9
Total Hardness		1 Aº
Temporary Hardness		1 Aº
Permanent Hardness		0 Aº
Water's Class, according to the International Hydrogeologists Union's (IHU) Standards: hot mineral water with sodium, bicarbonate, and chloride.		

III. RESULTS AND DISCUSSIONS

The results of the sustainability evaluation of the Asılbeyli-Kırklareli geothermal energy source based on the identified four goals in this study are mentioned below.

The well can be capable of heating 340 houses that is convenient to the Goal#1, clean energy. The use of the geothermal source for house heating would affect the community via supplying affordable, reliable, sustainable, and modern energy use, and increase substantially the share of renewable energy in the total energy mix of Turkey, contributing to the UN's targets for 2030 as convenient to the Goal#7 and Goal #11 [7]. Moreover, house heating benefits with geothermal energy sources are pointed as the use of national and clean energy, modularity, high efficiency, easy to use, lower transportation and maintenance costs, and diversity of usage. Besides its benefits, there might be some limitations during house heating by geothermal source usage, which can be listed as geothermal fluid composition, wellhead flow, usage density, source temperature, the distance between the wells, and the usage area [22]. Distance between the well and usage areas set the limit between source temperature and fluid temperature, which reaches to houses to be heated. This limitation has to be balanced while choosing the houses to be heated by their locations. Furthermore, 340 houses in Kırklareli may cover some number of villages that are already using coal for heating. Using geothermal energy will improve the air quality of the city by avoiding significant emissions such as particulate matter, CO_2, CO, SO_X, and NO_X, causing severe air pollution occurring by coal combustion. Moreover, 2,38 MWt capacity can utilise 0,124% of the annual electricity demand of Kırklareli city [23], which is convenient to the Goal#1, clean energy.

The potential of the well is convenient for 12,500 m^2 area of green housing, which benefits directly to the agriculture, whereas indirect environmental and economic benefits are convenient to the Goal#2, zero hunger, and Goal #3, Economic growth and well-being. Geothermal energy has several advantages such as: relatively cheaper than fossil and other alternative energy sources, it is reliable and has no risks of fire or explosion, needs minimum space compared to hydro or photovoltaic, the installation is easier and faster, shorter operation and maintenance time (6 months to 1 year) and has long facility life. Moreover, the use of geothermal resources for green housing is crucial and has various advantages comparing to the other energy sources. Proper heating system could increase the insemination efficiency that causes the efficiency increase of the whole greenhouse system up to 50-60%. [24]. Pumping carbon dioxide from the geothermal resource into greenhouses also increases the efficiency up to 40% via positive effect to photosynthesis. Additionally, the ideal temperature gives the opportunity of production without synthetic growth hormones to the plants [25]. Since Kırklareli has a

significant agriculture potential, green housing heating by geothermal source can contribute Region's sustainable agriculture production. This potential also matches up with UN's Goal#2 which has been established as, "ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that helps maintain ecosystems, strengthens capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality" and Goal #7 as "ensure access to affordable, reliable, sustainable and modern energy for all" [7].

Goal#3, Economic growth and well-being is correlated with the thermal tourism potential of the source for the 2,600 individuals. Tourism activities may have a positive impact on the Region's economy and recognition of Kırklareli that is one of the requirements for the socio-economic development of the city. Furthermore, the direct use of geothermal energy can also provide local employment opportunities. There is also an ongoing thermal hotel project at Saray-Tekirdağ in the same region for 3,000 individuals and has similar potential with Asılbeyli well as 2.5 MWt equivalent energy potential, 13,158 m^2 of green housing and 358 household heating [26]. Asılbeyli may be another thermal tourism centre in the Thrace Region with a capacity of 2,600 individuals.

Avoiding the pollution of the environment is one of the main purposes of the Goal#4, clean water. The environmental impacts cover the disruption of the atmosphere, water, and soil owing to waste issues. Conservation of water resources for the determined beneficial use purposes, e.g., potable, irrigational, reinjection process of the geothermal reservoir is obligatory. For the prevention of both surface and underground water sources from contamination with heavy metals and other pollutants, reinjection and filtration should be applied to the geothermal fluid. These are also parallel with the UN's target for 2030, which includes "improving water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater, and substantially increasing recycling and safe reuse of water globally" [7]. Therefore, water analysis of the geothermal resources has to be evaluated carefully for environmental sustainability. According to the water analysis of the well in Asılbeyli Na, Cl, Pb, Zn, Cu, Ni, B are within the limits of the World Health Organization (WHO) standards for direct usage of agricultural purposes. However, fluoride is detected higher than the standard level of 1.5 mg/l of the WHO standard, [27] for potable water, which should be taken into consideration for public health.

Moreover, Yılmaz and Kaptan [28] pointed out the adverse environmental effects of geothermal plants, especially Boron toxicity, heavy metals, and microclimatic changes due to the downhole fluid generated during the drilling, stimulation, and production phases. The main environmental problems were mentioned as the poisoning of both surface and groundwater, and harming the local vegetation in the study.

Another study from Kömürcü and Akpınar [29] states that certain treatment techniques of the waste fluid has to be applied in order to minimise environmental problems caused by geothermal energy usage, and the reinjection of the waste water is essential for both environmental and reservoir protection. Dumanoğlu, [30] has recently investigated H_2S concentrations in the air near Aydın and Manisa, where the majority of the geothermal power plants based, and found the concentrations were below the limit, but it has to be monitored continuously due to increase in production.

Furthermore, Tut Haklıdır [31] stated that the sustainability of geothermal reservoir relies on optimum geothermal fluid production which is possible with reservoir protection, well optimization, reservoir pressure control and effective reinjection scenarios in the geothermal field. Also, geothermal reservoirs have various thermodynamic conditions that require continuous hydrogeochemical monitoring [31].

The selected goals in this study basing on the UN's sustainable goals are summarised with Table 2.

Table 2. Goals selection for Kırklareli City

Selected Goals From UN's Goals For 2.38 MWt Source At Kırklareli Cıty [21]	**UN'S Sustainable Development Goals [7]**
GOAL 1: Clean energy for sustainable city for heating of 340 Houses	Goal #7: Affordable and Clean Energy
	Goal #11: Sustainable Cities and Communities
GOAL 2: Zero hunger for 12,500 m^2 capacity of green housing	Goal #2: Zero Hunger
	Goal #7: Affordable and Clean Energy
GOAL 3: Economic growth and well-being for 2,600 people capacity of geothermal tourism	Goal #3: Good Health and Well-being
	Goal #8: Decent Work and Economic Growth
GOAL 4: Clean water preserving water for sustainability of the source via reinjection for all utilisations	Goal #6: Clean Water and Sanitation

IV. CONCLUSION

Increasing the use of renewable energy and sustainable use of all the energy sources would be permanent solutions for energy-related global current and future problems. As a renewable energy source, geothermal energy is offered as an alternative to fossil fuels. However, the use of geothermal energy sources has environmental impacts as all other energy sources. Sustainability should also be applied to renewable energy use as well as conventional fossil energy use via systematic applications of sustainable development. Sustainable geothermal energy is possible if the precautions can be applied to avoid negative impacts even before utilising it. The precautions have to be taken by following the indicators and corresponding sustainable development goals from the discovery phase to the end of life.

In this study, Asılbeyli-Kırklareli geothermal energy source was evaluated based on the location-based sustainable development goals identified by the UN [7]. Sustainable utilisation of the geothermal energy source will contribute the environmentally friendly renewable energy use in Kırklareli. This approach would also be widespread to the other types of renewable energy sources, especially wind, hydro, and biomass power plants. Hence, precautions and decisions have to be made within a sustainable development framework considering the identified goals.

This study is important and contributes to science by taking attention to the environmental effects of renewable energy sources and in terms of identifying the criteria for evaluating the source for a sustainable development approach, particularly via defining the related location-based goals. In the decision-making process, attention should be drawn to the assessment criteria for a sustainable renewable energy supply approach. Some of the other remaining goals, such as "ensure sustainable consumption and production patterns and take urgent action to combat climate change and its impacts," may also be evaluated for all geothermal energy resources to be used in a sustainable manner; those may be the subject of a future work.

ACKNOWLEDGEMENT

The authors are grateful to Lütfi Taşkıran from the Turkish General Directorate of Mineral Research and Exploration (MTA) for the support and data provided for this paper.

REFERENCES

[1] REN21 Secretariat, (2018), Renewables 2018 Global Status Report, Paris. ISBN 978-3-9818911-3-3.

[2] Erdil, A., Erbıyık, H., (2015). Renewable energy sources of Turkey and assessment of sustainability, *Procedia Social and Behavioural Sciences*, 207, 669-679. doi: 10.1016/j.sbspro.2015.10.137.

[3] Olabi, A. G. (2014). 100% Sustainable energy. *Energy*, 77, 1-5. doi:10.1016/j.energy.2014.10.083.

[4] Connolly, D., Lund, H., Mathiesen, B. (2016). Smart energy Europe: The technical and economic impact of one potential 100% renewable energy scenario for the European Union. *Renewable and Sustainable Energy Reviews*, 60, 1634-1653. doi:10.1016/j.rser.2016.02.025.

[5] WCED, (1987). Our Common Future, Report of the World Commission on Environment and Development, Oxford University Press, New York, USA.

[6] Lund H. (2014). Renewable energy systems, ISBN 978-0-12-410423-5.

[7] UN, (2017). Global indicator framework for the Sustainable Development Goals and targets of the 2030 Agenda for Sustainable Development. A/RES/71/313, Retrieved May 2, 2019, from https://unstats.un.org/sdgs/indicators/indicators-list/

[8] Irena, (2017). Geothermal Power: Technology Brief, International Renewable Energy Agency, Abu Dhabi.

[9] Lee K. C. (1996). Classification of geothermal resources-an engineering approach, *Proceedings of the Twenty-First Workshop Geothermal Reservoir Engineering*. January 22-24.

[10] Rybach, L. (2007). Geothermal Sustainability. *Geo-Heat Centre Quarterly Bulletin*. Vol. 28 No:3 ISSN 0276-1084

[11] UN, (2001). Indicators of Sustainable Development: Guidelines and Methodologies. Retrieved May 10, 2019, from https://sustainabledevelopment.un.org/content/documents/indisd-mg2001.pdf

[12] Evans, A., Strezov, V., Evans, T. J. (2009). Assessment of sustainability indicators for renewable energy Technologies, *Renewable and Sustainable Energy Reviews*, No: 13(5), pp. 1082-1088. doi:10.1016/j.rser.2008.03.008.

[13] Santoyo-Castelazo, E., Azapagic, A. (2014). Sustainability assessment of energy systems: Integrating environmental, economic and social aspects. *Journal of Cleaner Production*, No: 80, p.p. 119-138. doi:10.1016/j.jclepro.2014.05.061.

[14] Shortall, R., Davidsdottir, B., Axelsson, G. (2015). A sustainability assessment framework for geothermal energy projects: Development in Iceland, New Zealand and Kenya. *Renewable and Sustainable Energy Reviews*, No:50, p.p. 372-407. doi:10.1016/j.rser.2015.04.175.

[15] ETKB, (2010). Enerji ve Tabii Kaynaklar Bakanlığı 2010-2014 Strategic Development Plan. Ankara. Retrieved from http://www.sp.gov.tr/tr/stratejik-plan/s/269/Enerji+ve+Tabii+Kaynaklar+Bakanligi+ 2010-2014, accessed on: 01.05.2019.

[16] ETKB, (2017). Enerji ve Tabii Kaynaklar Bakanlığı 2015-2019 Strategic Development Plan. Ankara. Retrieved from https://sp.enerji.gov.tr/sp-2015-2019.html, accessed on: 01.05.2019.

[17] ETKB, (2014). Enerji ve Tabii Kaynaklar Bakanlığı, National Course of Action for Renewable Energy. Ankara. Retrieved from http://www.enerji.gov.tr/tr-TR/Bakanlik-Haberleri/Ulusal-Yenilenebilir-Enerji-Eylem-Plani- accessed on: 01.05.2019.

[18] Melikoglu, M. (2017). Geothermal energy in Turkey and around the World: A review of the literature and an analysis based on Turkeys Vision 2023 energy targets. *Renewable and Sustainable Energy Reviews*, No: 76, p.p. 485-492. doi:10.1016/j.rser.2017.03.082

[19] Hepbasli, A., Canakci, C. (2003). Geothermal district heating applications in Turkey: A case study of Izmir–Balcova. *Energy Conversion and Management*, 44(8), 1285-1301. doi:10.1016/s0196-8904(02)00121-8

[20] MTA, (2017). Türkiye Jeotermal Enerji Potansiyeli ve Arama Çalışmaları, Trakya Jeotermal Etüt Çalışmaları. *General Directorate of Mineral Research and Exploration (MTA)*, Retrieved from http://www.mta.gov.tr/v3.0/arastirmalar/jeotermal-enerji-arastirmalari, accessed on: 19.04.2019.

[21] MTA, (2017). "Kirklareli-Merkez Ar: 201339002, Ar: 201339003 ve Ar: 201339004 No.lu Jeotermal Kaynak Arama Ruhsat Sahalari Jeotermal Etüt (Jeoloji-Jeofizik) ve Kma- 2014/2 Jeotermal Gradyan, Kma-2014/7 Jeotermal Araştirma Sondajlari Kuyu Bitirme Raporu" *General Directorate of Mineral Research and Exploration (MTA)*, November 2017.

[22] Altaş, S. (2010). Kızılcahamam Jeotermal Merkezi Isıtma Sistemi ile Klasik Merkezi Isıtma Sisteminin Karşılaştırılması, Master Thesis, Gazi Üniversitesi, Fen Bilimleri Enstitüsü, Ankara.

[23] Özer, B., Kızılay, S. (2018). A Research on Geothermal Energy Potential in Kırklareli City of Turkey: Is It Actually Sustainable? *Proc. 3rd International Conference on Organic Electronic Material Technologies (OEMT2018)*. pg. 267–278. Sep 20-22, 2018, ISBN: 978-605-68918-1-6

[24] Hasdemir, M, Gül, U, Hasdemir, M, Yasan Ataseven, Z. (2015). Jeotermal Sera İşletmelerinin Bilgi Kaynakları. *Tarım Ekonomisi Araştırmaları Dergisi*, 1 (2), 42-51. Retrieved from https://dergipark.org.tr/tr/pub/tead/issue/12731/155081

[25] Kendirli, B, Çakmak, B. (2010). Yenilenebilir Enerji Kaynaklarının Sera Isıtmasında Kullanımı. *Ankara Üniversitesi Çevrebilimleri Dergisi,* 2 (1), 95-103. DOI: 10.1501/Csaum_0000000029

[26] MTA, (2018). "Tekirdağ-Saray Ar: 2012590004 No.lu Jeotermal Kaynak Arama Ruhsat Sahasi Jeotermal Etüt (Jeoloji-Jeofizik) ve Ts-2015/1 Jeotermal Araştırma Sondajı Kuyu Bitirme Raporu. *General Directorate of Mineral Research and Exploration (MTA)*, Retrieved from https://eticaret.mta.gov.tr/index.php?route=product/product&product_id=20965 accessed on: 01.07.2020.

[27] WHO, (2017). Guidelines for Drinking-water Quality, Fourth Edition Incorporating the First Addendum. Geneva, pg.371., *World Health Organization (WHO)*, License: CC BY-NC-SA 3.0 IGO. ISBN 978-92-4-154995-0)

[28] Yilmaz, E., Kaptan. M.A. (2017). Environmental impact of geothermal power plants in Aydın, Turkey. *EEMS 2017, E3S Web of Conferences 19, 02028* doi:10.1051/e3sconf/20171902028

[29] Kömürcü, M. I.,Akpınar, A. (2009). Importance of geothermal energy and its environmental effects in Turkey. *Renewable Energy*, 34(6), 1611-1615. doi:10.1016/j.renene.2008.11.012

[30] Dumanoglu, Y.,2020. Monitoring of hydrogen sulfide concentration in the atmosphere near two geothermal power plants of Turkey, *Atmospheric Pollution Research*, doi.org/10.1016/j.apr.2020.08.015

[31] Tut Haklıdır F.S. (2020), The importance of long-term well management in geothermal power systems using fuzzy control: A Western Anatolia (Turkey) case study, *Energy*, Vol. 213, ISSN 0360-5442, doi:10.1016/j.energy.2020.118817.