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Assessment of Geothermal and Solar Hybrid Power Generation Technologies in Turkey and Its Application to Menderes Graben

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ABSTRACT

The basis of this study is the widespread existence of low enthalpy geothermal resources in Turkey. The usage of low enthalpy geothermal resources in balneology, district heating and green house heating has made Turkey one of the primary consumer of geothermal energy in the world. However, the utilization of low enthalpy geothermal resources in geothermal-solar hybrid systems for electricity generation, which is the unique focus of the analysis in this work, has not received sufficient attention so far. The study thus fills the gap in the literature by defining potential sites for this type of hybrid systems based on geography specific data. The proposed method comprises the development of a solar parabolic troughs-ORC geothermal enhancement technology for superheating binary cycle fluids to higher temperatures thereby increasing their enthalpy for more feasible energy conversion. Since the hybrid technology cannot be considered in isolation from geological aspects, the proposed method assesses the distributed geothermal and solar hybrid potential of Turkey through the use of geographic information systems. After compiling a detailed inventory of geothermal data, low enthalpy geothermal resources are mapped. Considering the possibility of transmission of geothermal fluids, buffer zones are assigned. Regions that are suitable for solar power plant implementation are intersected by buffer zones. After each region is checked for its direct solar radiation value, the map addressing the potential regions suitable for this hybrid technology is obtained. The data of the selected location from GIS application is used in a mathematical model of an already existing-hybrid system, which was developed, and power output of the system is calculated. Considering the fact that the main player in Turkish electricity production market is natural gas with a 31.9% share, the annual amount of saved carbon and money is calculated when that amount of power is produced from local geothermal-solar sources rather than imported natural gas.

1. INTRODUCTION

1.1 Overview

Through the human history, engineering has contributed to the advance of civilization. Starting from the ancient ages, innovations of engineers have had an earth-shattering effect on world's people. The mavels of Modern era were machines, steam engine facilitated mining, powered trains and ships, whereas the great achievements of 20th century were widespread distribution of clean water and electricity, radio, television, computer and internet. With the development of telecommunication, the accomplishments in all branches of science become largely universal, timely parallel and relatively globally available. Within all of these advances, the problem of sustaining the needs of growing population, to ensure the 'future' with the finite resources of Earth, has occurred [1].

The increase in the concentration of CO_2 which leads to the average temperature rise in the atmosphere, the melting of polar ice caps and the worldwide seen extreme weather events are the evidences of Earth's disturbed balance. In other words, 6.5 billion people consume and pollute far more than Earth can sustain. Thus the grand challenges that wait the engineers of 21th century highlight the need to develop new sources of energy while reversing the degradation of environment [1]. A breakthrough in this area can revolutionize the way we live.

This study aims to assess the possibilities in Turkey for combining new technologies in renewable energy, specifically in geothermal and solar energy. Employing such carbon-free sources can help to combat climate change by lowering the extensity of fossil fuel combustion. The encouraging results may allay the concerns of investors and decision makers about the intermittent nature and high cost of solar and untapped potential of low enthalpy geothermal resources.

1.2. Motivation

Turkey, strategically positioned at the crossroads of Asia, Europe and the Middle East, is heavily dependent on expensive imported energy sources such as natural gas and crude oil that place a big burden on Turkish economy. On the other hand, air pollution has become a great environmental concern since these sources provide energy through combustion. With the increasing energy demand mainly caused by Turkey's economic growth of 8.9 percent in 2011 and 2.2 percent in 2012 [2], sustainable supply became a problem, cannot be ignored. As a solution, a major renewable energy and energy efficiency program has been embarked in the country. The target is set to increase clean energy share at least to 30% of Turkey's power supply by 2023-the 100th anniversary of Turkish Republic. Another goal stated in the strategy paper of security supply is to decrease natural gas share in power supply to 30% [3]. The motivation behind the present study is to contribute to the achievement of that objective by narrowing the gap in the literature and highlighting the ignored electricity production capacity of low temperature geothermal resources.

1.3. Current Geothermal Power Situation in Turkey

In the world, many countries have significant geothermal resources especially the ones located within the framework of plate tectonics. These places are along 'Ring of Fire', 'spreading centers, continental rift zones and other hot spots'. Turkey is one of these countries. It is located on the Mediterranean part of Alpine-Himalayan Tectonic Belt, which is a young belt presenting important geothermal potential. The horst-graben system in Western Anatolia, widespread volcanism, the active tectonics in Central and Eastern Anatolia and right lateral and strike slip North Anatolian Fault Zone affect the distribution of the geothermal regions in the country [4].

Parallel to its potential, Turkey is not a new player in geothermal energy market. General Directorate of Mineral Research and Exploration (MTA) started geothermal resource exploration in 1960's in Turkey and the first geothermal power plant, Kızıldere, was installed in 1984 [4]. However these studies came to a standstill due to the improper policies. With the new millennium, global ambition to decrease CO2 increased. Kyoto protocol, an international agreement contract that places restrictions on countries to reduce the emission of greenhouse gases, was put into operation in 2005 and Turkey signed it in February 2009. Increase in the fuel prices became another accelerator to switch to renewable energy sources.

In 2005, related changes have started to be done in energy laws. Law no.5346 was put into force in 10.05.2005 [6]. Table 1 clearly shows the effect of the new law about the utilization of renewable energy sources in power production on specifically geothermal electricity production capacity of Turkey [5].

Table-1: Top 5 countries in terms of increase in electricity production from geothermal [5]

Country	MW	GWh	%MW	%GWh
USA	496	-2.314	19	-14
Indonesia	400	3.515	50	58
Iceland	373	3.114	184	210
New Zealand	193	1.281	44	46
Turkey	62	385	308	368

In Table-1, the second column represents the difference in capacity (MW) between years 2005-2010. Similarly, the difference in produced energy between 2005 -2010 is given in units of GWh in the third column.

Electricity production from renewable energy sources is supported by law no. 6094 that put in place in 29.12.2010. In accordance with law no.5346, the 'take or pay price' of electricity generated by geothermal energy is 10, 5 US $ cent/kWh [5]. The government incentives and the growth potential started to draw attention to Turkey. Foreign investors have started to see major business development opportunities not only in geothermal but also in solar, wind, hydro and all elements of energy efficiency. Over $40 billion investment is expected in this area by 2020 [7]. 14 geothermal sites suitable for power production and 58 geothermal sites to be used for heating and thermal tourism purposes are handed on domestic and foreign investors by General Directorate of Mineral Research and Exploration (MTA) in return for 457.209.050 US$ [8].

The number of the geothermal sites in Turkey is 207 [8]. As of June 2013, there are 24 power production licensed geothermal sites with a total 'capacity in operation' of 114.2 MWe. The total 'capacity under construction' is 391.49 MWe. Names of the companies, locations and other details are listed in Table-2 [9].

Table-2: Different staged-Geothermal Power Plants in Turkey [9]

Company Name	GEPP Name / Location	Capacity (MWm)	Licensing Date	Capacity under Construction (MWe)	Capacity in Operation (MWe)
İn-Altı Termal Turizm Sağlık Tekstil Gıda ve Temizlik Maddeleri San. ve Tic. Ltd. Şti.	Gök JES / Sarayköy-Denizli	3	20.09.2012	3	0
Menderes Geothermal Elektrik Üretim A.Ş.	Dora 4 JES/ Salavatlı-Aydın	17	05.09.2012	17	0
Türkerler Jeotermal Enerji Arama ve Üretim A.Ş.	Sarıkız JES/ Alaşehir-Manisa	10	15.08.2012	10	0
Ken Kipaş Elektrik Üretim A.Ş.	Ken Kipaş JES/ Yılmazköy-Aydın	24	15.08.2012	24	0
Maren Maraş Elektrik Üretim Sanayi ve Ticaret A.Ş	Maren 2 JES/ Bozköy-Aydın	24	09.05.2012	24	0
Mtn Enerji Elektrik Üretim San. ve Tic. Ltd. Şti.	Babadere JES/ Ayvacık-Çanakkale	3	10.03.2012	3	0
Türkerler Jeotermal Enerji Arama ve Üretim A.Ş.	Türkerler Alaşehir JES/ Alaşehir-Manisa	24	01.02.2012	24	0
Jeoden Elektrik Üretim İnşaat Sanayi ve Ticaret A.Ş.	Sarayköy-Denizli	2,52	23.11.2011	2,52	0
Zorlu Jeotermal Elektrik Üretim A.Ş.	Alaşehir JES/ Alaşehir-Manisa	30	28.07.2011	30	0
Kiper Elektrik Üretim A.Ş.	Kiper JES/ Nazilli-Aydın	20	28.07.2011	20	0
Çelikler Jeotermal Elektrik Üretim A.Ş.	Sultanhisar JES/ Sultanhisar-Aydın	9,9	26.05.2011	9,9	0
Çelikler Jeotermal Elektrik Üretim A.Ş.	Pamukören JES/ Pamukören-Aydın	61,72	26.05.2011	61.72	0
Gümüşköy Jeotermal Enerji Üretim Anonim Şirketi	Gümüşköy JES/ Gümüşköy-Aydın	15	24.02.2011	15	0

ALRES ENERJİ ÜRETİM A.Ş.	Atça-Aydın	9,5	28.12.2010	9,5	0
Karkey Karadeniz Elektrik Üretim A.Ş.	Umurlu-Aydın	5	06.09.2010	4,85	0
Santral Enerji Üretimi Sanayi ve Ticaret A.Ş.	Caferbeyli-Manisa	15	19.08.2010	15	0
Menderes Geothermal Elektrik Üretim A.Ş.	Dora 3 JES/ Salavatlı-Aydın	34	19.08.2010	34	0
Maren Maraş Elektrik Üretim Sanayi ve Ticaret Anonim Şirketi	Hıdırbeyli-Aydın	44	30.07.2009	24	20
Zorlu Doğal Elektrik Üretimi A.Ş	Kızıldere-Denizli	75	21.08.2008	60	15
Menderes Geothermal Elektrik Üretim A.Ş.	Salavatlı-Aydın	9,5	27.12.2007	0	9,5
Tuzla Jeotermal Enerji Anonim Şirketi	Ayvacık-Çanakkale	7,5	11.05.2004	0	7,5
Gürmat Elektrik Üretim A.Ş.	Germencik-Aydın	47,4	23.03.2004	0	47.4
Bereket Jeotermal Enerji Üretim A.Ş	Sarayköy-Denizli	7,06	17.07.2003	0	6,85
Menderes Geothermal Elektrik Üretim A.Ş.	Salavatlı-Aydın	7,95	04.04.2003	0	7,95

The resource temperatures in these areas are in a range of about 242-140˚C. It is an indicator of the fact that the majority of Turkey's geothermal potential, specifically 94% [8], is low enthalpy i.e. low ability to do thermodynamic work, resources.

Figure-1 shows the distribution of geothermal regions over Turkey [10]. In Turkey, low enthalpy resources' utilization has been almost restricted to balneology, greenhouse heating and district heating. That carried Turkey to top-ranks in related worldwide lists as stated in Table-3 while its total energy use is 2,084 MWt and 36,885.9 TJ/yr, as stated in Table-4 [13] .Nevertheless, regarding indirect utilization ways, Turkey cannot be seen among top five countries (USA, Philippines, Indonesia, Mexico, Italy; respectively) worldwide [5].

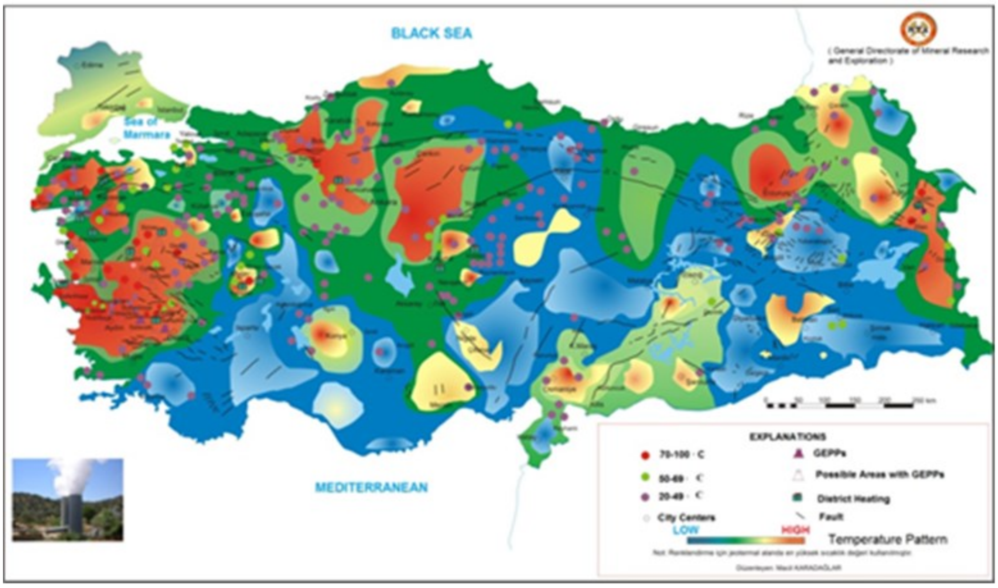

Figure 1: Geothermal resources of Turkey and their utilization ways [10]

Table-3: The top 5 countries in different direct applications of geothermal resources [13]

Balneology	Greenhouse Heating	District Heating
China	**Turkey**	Iceland
Japan	Hungary	China
Turkey	Russia	**Turkey**
Brazil	China	France
Mexico	Italy	Russia

Table-4: Total Annual Energy Use in Direct Use Applications of Geothermal Resources in Turkey [13]

	Annual Energy Use in MW_t	Annual Energy Use in TJ/yr
Greenhouse Heating	483	9,138
Individual Space Heating	219	2,417
District Heating	792	7,386.4
GHPs	38	536.5
Bathing &Swimming	552	17,408

The total energy use is 2,084 MWt and 36,885.9 TJ/yr [13].

1.4 Current Solar Power Situation in Turkey

Due to the relative motion of Sun with respect to Earth, the amount of the intercepted solar energy changes from place to place. In this study, among the renewable energy sources, solar is selected to assist geothermal because Turkey has considerable solar potential as can be seen in Figure-2.

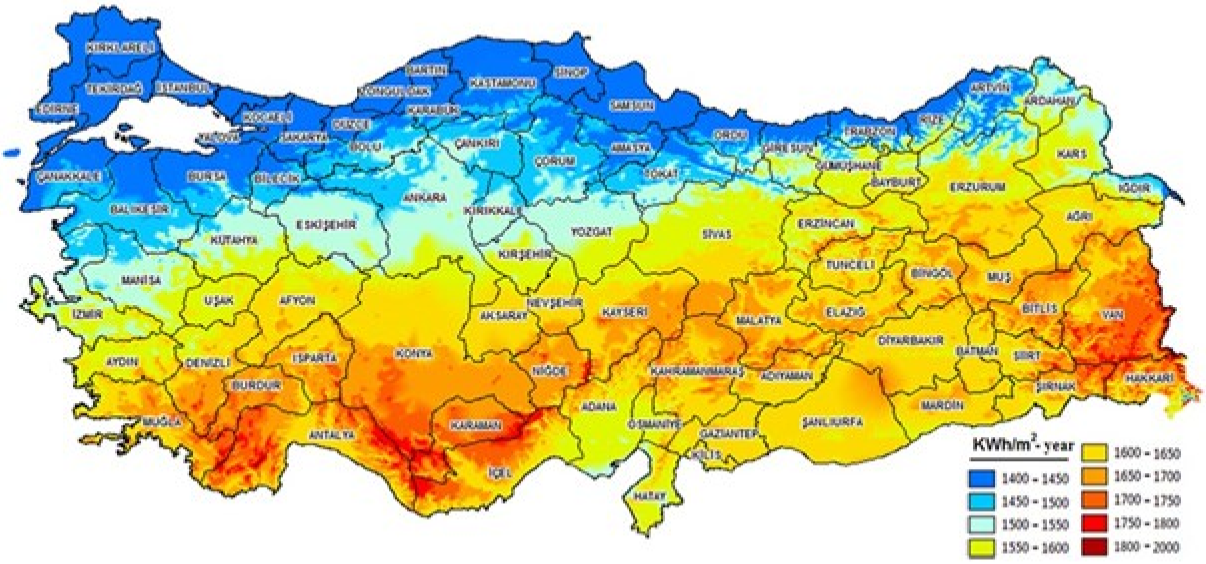

Figure 2: Map of solar potential of Turkey [15]

Global solar irradiance is the total of direct and diffuse solar radiation. Some technologies can use both direct and indirect radiation whereas some technologies can only use direct irradiance.

1.5. Research Problem and Objectives

For Turkey, one sustainable way to increase the clean energy share in the power generation is the utilization of low enthalpy geothermal resources. The subject of this study roots from the common existence of low enthalpy geothermal resources compared to high enthalpy ones. With today's technology, Organic Rankine Cycle (ORC) or Binary Cycle power plants and hybridization concepts are best energy conversion systems to exploit these resources, both from a technical and environmental point of view. In this study, a flash binary geothermal system combined with parabolic solar trough collectors (PTC) is analyzed. First objective is to address the potential regions having both solar and geothermal sources in Turkey. The second objective is to conduct an analysis to calculate the net power output of the system when the proposed geothermal-solar flash binary system by Andrew Greenhut [14], is employed in a hypothetical region in the city of Aydın.

2. DATA COMPILATION

2.1. Solar Data

Required solar data was purchased from General Directory of Renewable Energy-Republic of Turkey Ministry of Energy and Natural Resources. This data set includes daily and hourly solar insolation (i.e. incident energy per unit area on a surface, found by integration of irradiance over a specified time-1 day or 1 hour-) and is available for 13 different stations in Turkey. Since the analysis is carried out for a hypothetical site in Aydın, data set was gathered from Didim-Aydın station. Measurements were done for one year in 2011 and they include hourly global and diffuse irradiance in units of W/m2, ambient temperature (˚C) and sunshine duration. Since concentrating parabolic troughs which is the collector type of the solar part in the proposed hybrid system can utilize only the direct normal irradiance (DNI), DNI was calculated as the difference between global and diffuse solar irradiance. DNI map of Turkey is given in Figure-3 below. Total solar radiation, direct solar radiation and sunshine duration in Aydın are given as maps in Figure-4, Figure-5 and Figure-6 respectively.

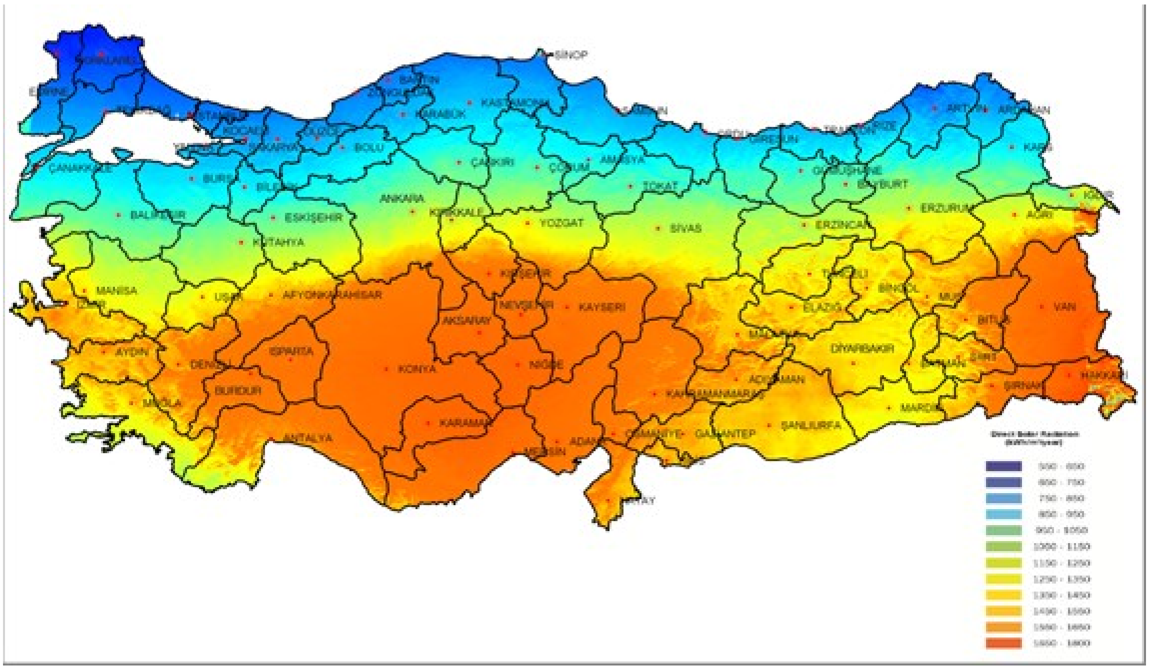

Figure 3: Direct solar radiation in Turkey [17].

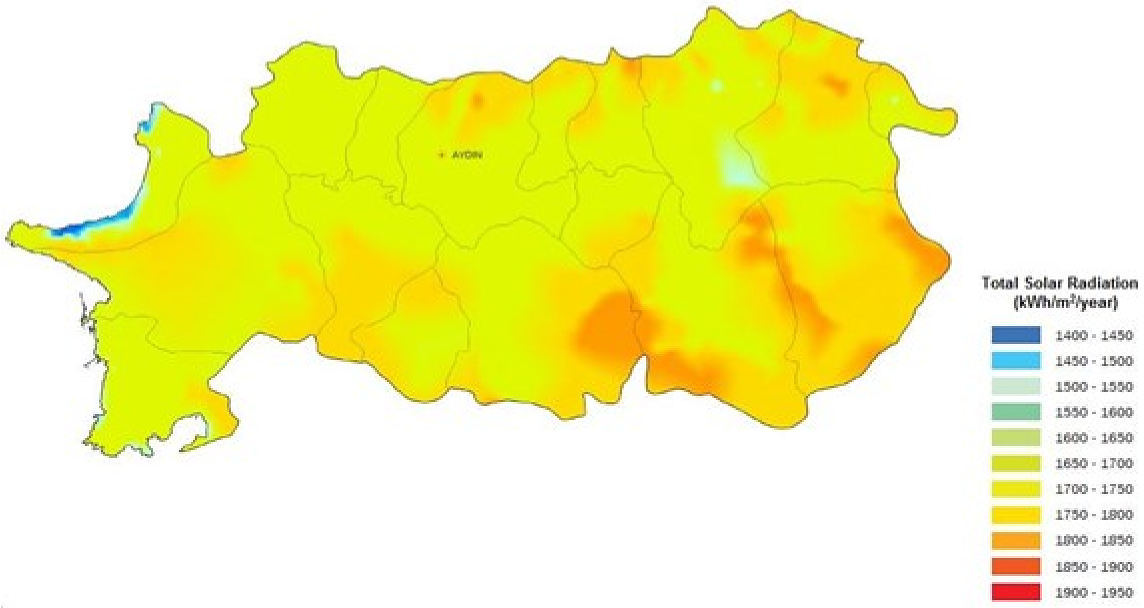

Figure 4: Total solar radiation in Aydın [17].

Since the proposed system utilizes solar energy via parabolic troughs, here direct solar radiation (i.e. beam resources) is a much more important parameter than total (i.e. global) solar radiation.

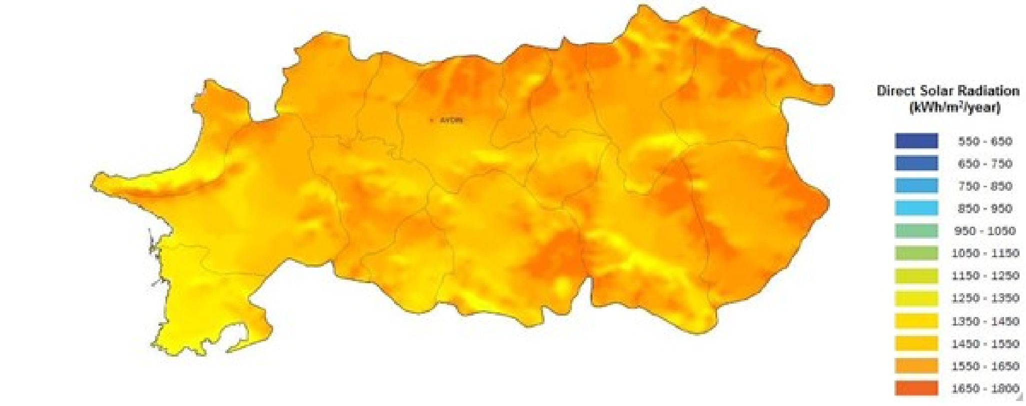

Figure 5: Direct solar radiation in Aydın [17].

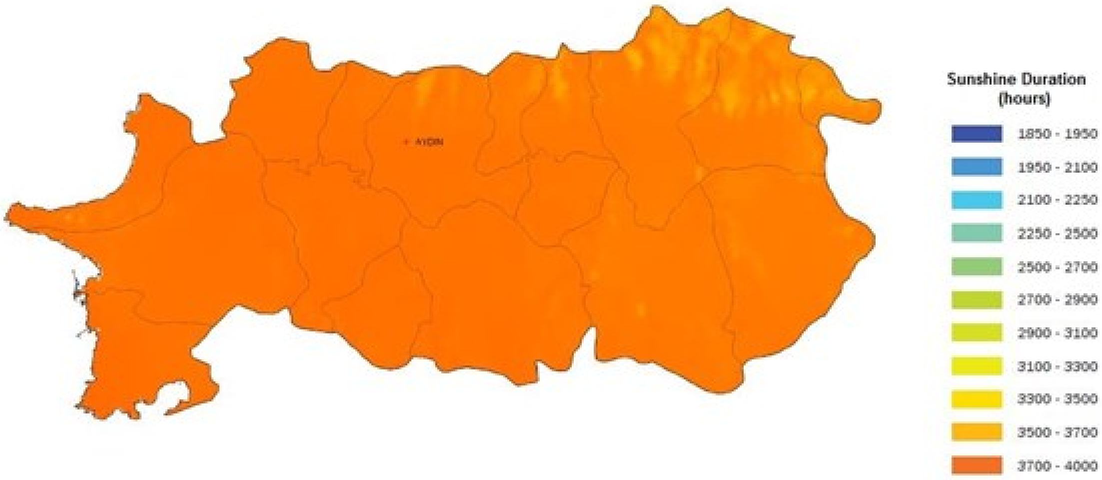

Figure 6: Sunshine duration in Aydın [17].

2.2. Geothermal Data

Geothermal data, including the chemical analysis of geothermal waters and well bottom or well head temperature, pressure, flow rate, production type and names of the wells, are obtained from the Inventory-201 published by Mineral Research & Exploration General Directorate in 2005 [18]. Coordinates of these geothermal fields are mainly gathered from geological data catalog which is published by TUBITAK-Marmara Research Center- Active Tectonics Research Group [20]. Geothermal sites with a temperature of 100°C or more were selected and listed.

Here it is also important to note that 100˚C was selected as lower temperature limit of geothermal resources because based on the study of Tester et.al. [21], the utilization efficiency for thermodynamic cycles as a function of geothermal fluid temperature for ten different working fluids is known for the brine temperatures between 100-200˚C.

This decision support system can provide guidance both for the investors and the authorities in identifying suitable locations. It can be a checklist controlling the practicability (i.e. workableness of this proposed technology). In regions with the appropriate prerequisites, this concept heralds considerable benefits in terms of electricity generation.

3. OBTAINED MAPS

To obtain a decision support system that can provide guidance both for the investors and the authorities, firstly, the geothermal regions with a minimum of 100˚ C were listed. Secondly, these regions are marked on general map of Turkey by using the software Mapinfo. Thirdly, obtained map was overlaid by direct solar radiation map since parabolic solar troughs can utilize only direct beam. There are 7 cities in Turkey with geothermal resources having a temperature of 100˚C or more. As a fourth step, these cities are examined in detail by checking whether their geothermal sites are intersecting with the sites suitable for solar power implementation or not. While doing this, transmission is also considered so buffer zones around geothermal wells are established. Finally, 57 geothermal points were checked and only Aydın-Ortaklar region was found suitable with a direct solar radiation value around 1450-1550 kWh/m^2/year. Ayvacık-Çanakkale was another place at which geothermal potential intercepts with solar but the direct solar radiation value here was around 950-1050 kWh/m^2/year.

3.1 General Maps

Figure 7: Google Earth map of Turkey with the highlighted geothermal spots with a temperature of minimum 100 ˚C

As can be seen in Figure-7, all the geothermal sites with a temperature of at least 100˚C exist in Western Anatolia, except Van-Erciş site.

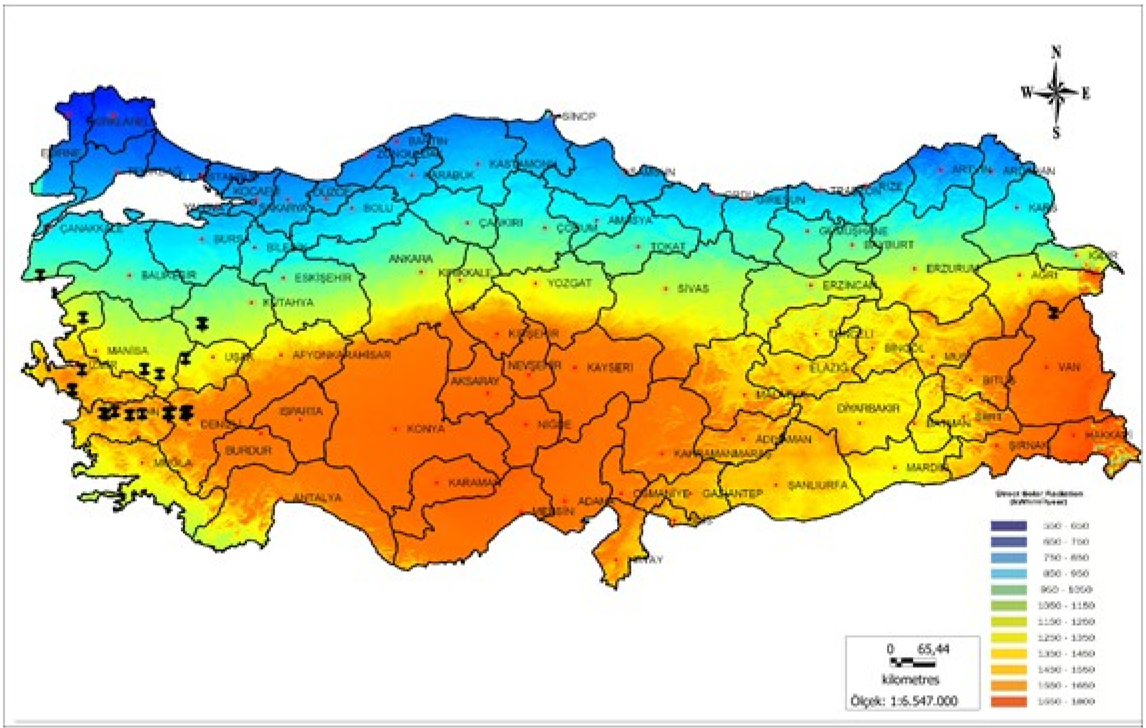

Figure-8: Direct solar radiation map with the black-pointed geothermal sites with a temperature of at least 100˚ C

Van-Erciş site, in Eastern Anatolia region, can be seen as a wild cat since it has a direct solar radiation value very close to Aydın. Nevertheless the quite low sunshine duration value of Erciş makes the implementation of geothermal solar thermal hybrid power system impossible here. The comparative maps of cities Aydın and Van can be seen in Figure- 9 and Figure-10 [17].

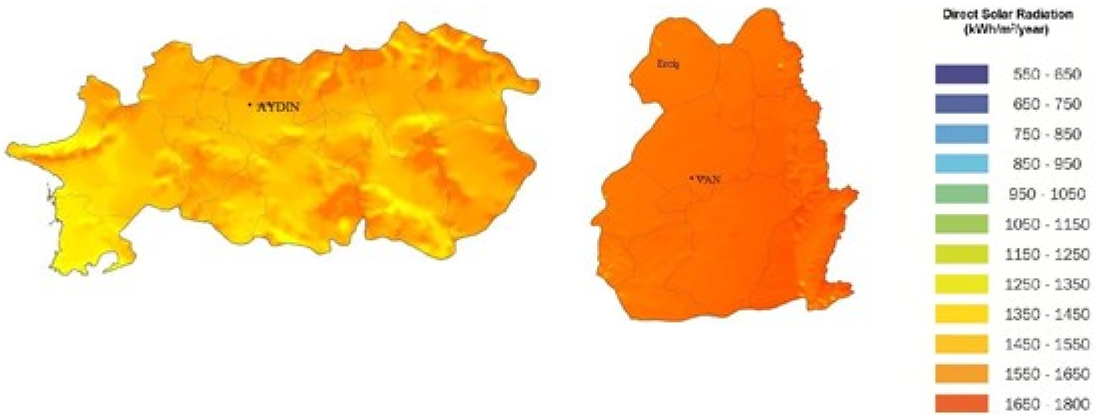

Figure 9: Direct solar radiation values of Aydın and Van (maps are not to scale) [17]

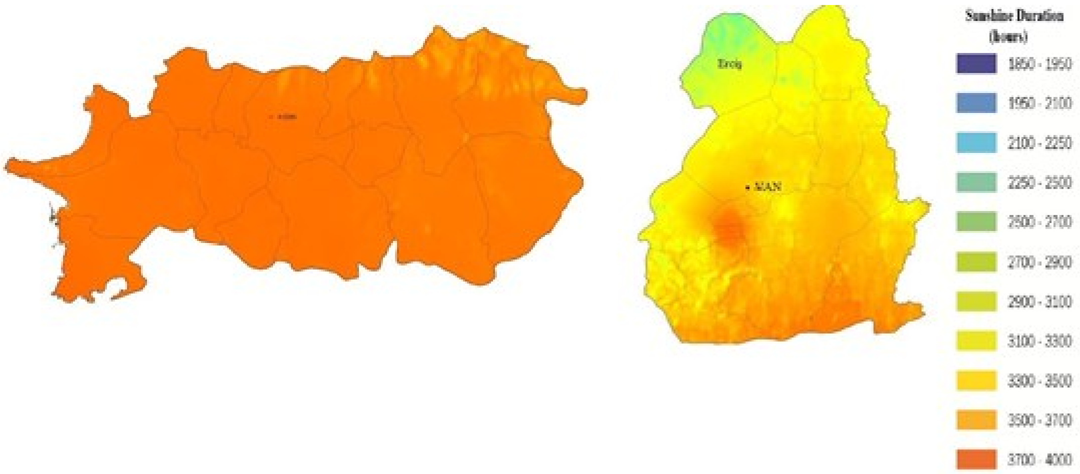

Figure 10: Sunshine duration values of Aydın and Van (maps are not to scale) [17]

3.2 Checklist for 7 Cities and Their Maps

Aydın, Çanakkale, Denizli, İmir, Kütahya, Manisa and Van are the cities that have geothermal resources with a minimum temperature of 100˚C. Their solar potential maps were obtained by General Directorate of Renewable Energy as Jpeg format. Thus each jpeg formatted-map was coordinated in Mapinfo as the margin of error was set to zero. Buffer zones are drawn as the center is geothermal well itself and the radius is 1 kilometer. Radius is set as 1 kilometer considering the cooling effect of geothermal fluid and transmission cost.

There are 7 constraints stated by General Directorate of Renewable Energy when unusable lands were mapped [17]:

1. Settlement area
2. Wet lands
3. Forests and agricultural lands
4. Natural protection zones
5. Railway, highway, harbor
6. Land slope must not exceed 3˚
7. Total solar radiation must not be smaller than 1650 kWh/m2/year

Maps of unusable lands for solar power plant installation are also coordinated and intersected by buffer zones of geothermal spots in Mapinfo. Well spots are colored as red and buffer zones are rounded by black circles. Following maps are due to scale as stated within the maps.

Aydın: There are mainly 6 geothermal sites namely; Gümüşköy, Ortaklar, Germencik, Ilıcabaşı, Salavatlı and Pamukören in Aydın. Only Ortaklar region is suitable for hybrid power plant in Aydın. Within the buffer zone, an area as green colored is caught representing a total solar radiation value about 1650-1700 kWh/m2/year as can be seen in Figure-11. When its direct solar radiation value is checked, it is seen as 1450-1550 kWh/m2/year.

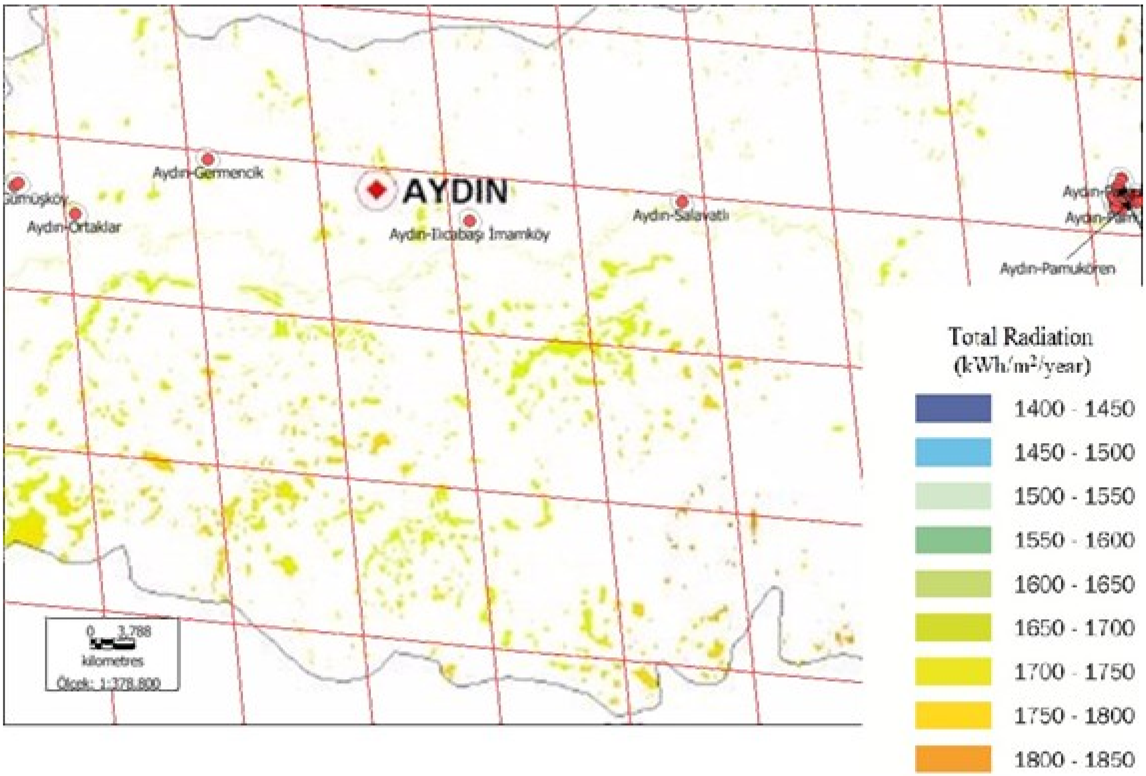

Figure 11: Map of usable lands (colored) intersected by buffer zones in Aydın

Çanakkale: Tuzla-Ayvacık was the only known geothermal site in the city. It intersects a usable solar region but the direct solar radiation is 950- 1050 kWh/m2/year here.

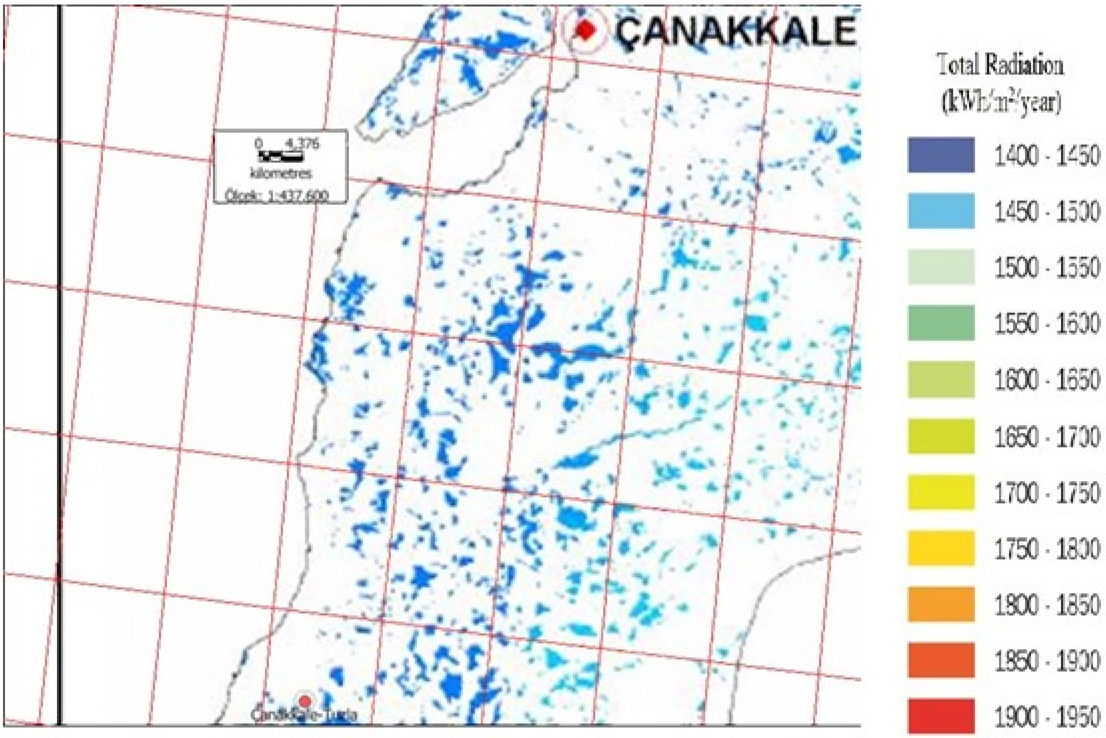

Figure 12: Map of usable lands (colored) intersected by buffer zones in Çanakkale

Denizli: None of the geothermal sites did catch usable solar region.

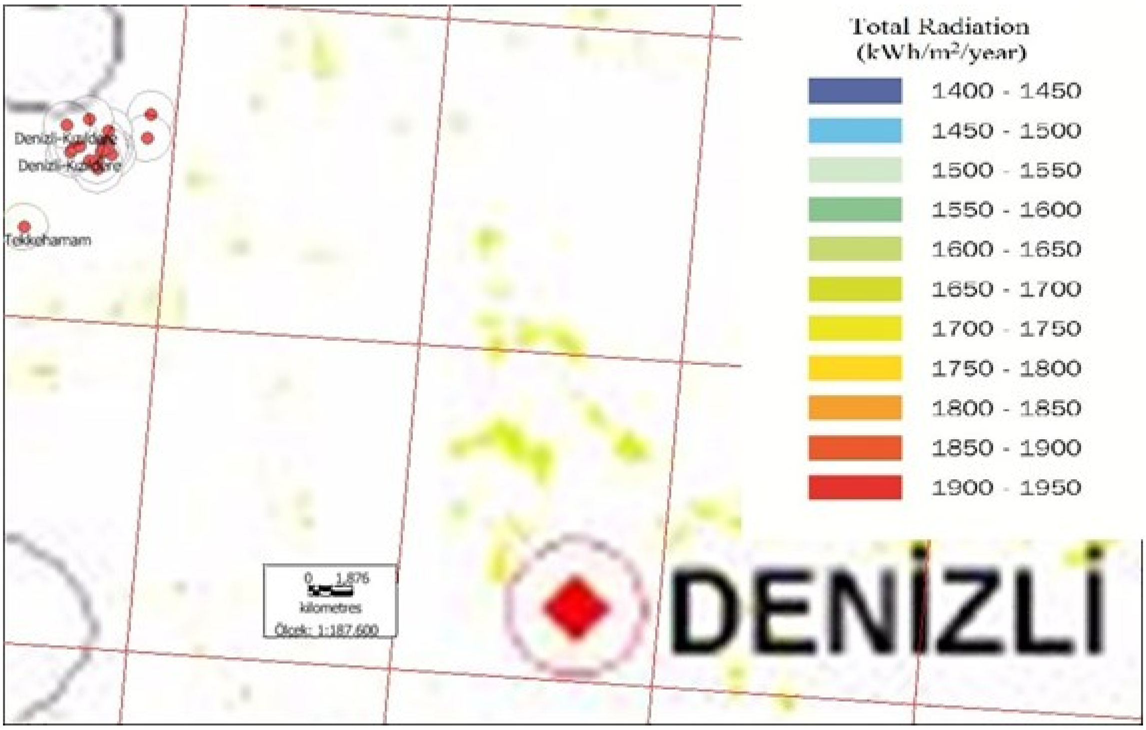

Figure 13: Map of usable lands (colored) intersected by buffer zones in Denizli.

İzmir: None of the geothermal sites in İzmir could catch any usable solar region.

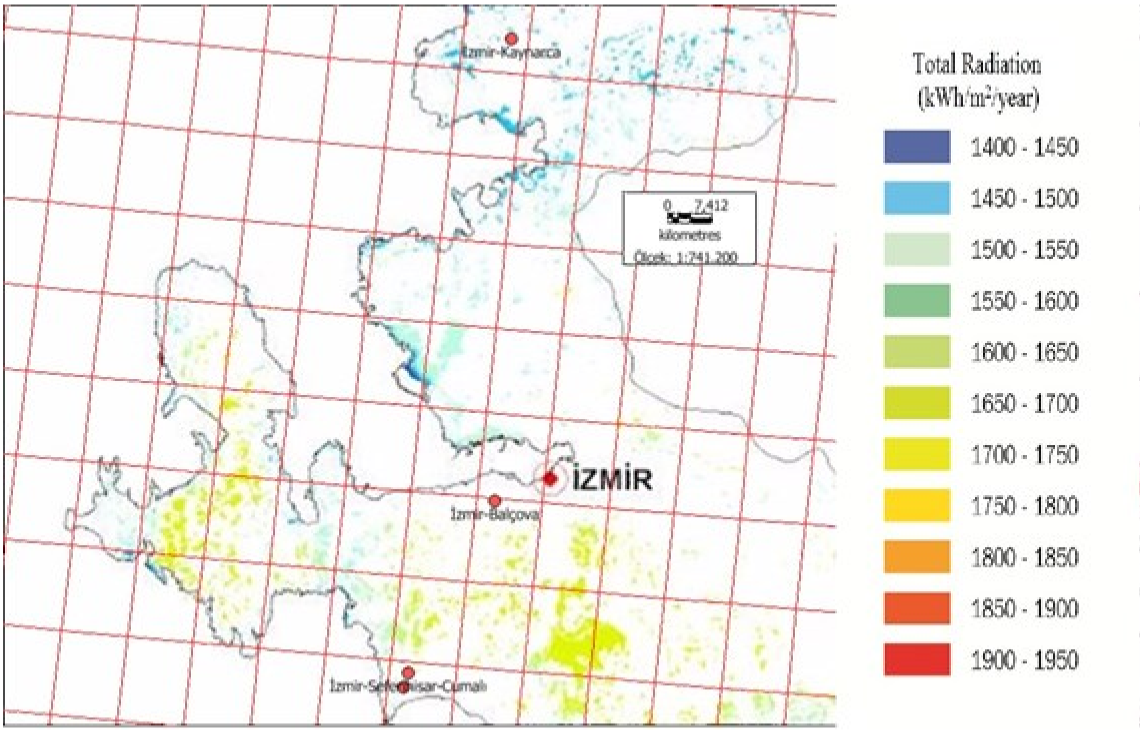

Figure 14: Map of usable lands (colored) intersected by buffer zones in İzmir.

Kütahya: There is only one geothermal site, Simav, that is examined in Kütahya and it did not match any usable solar region.

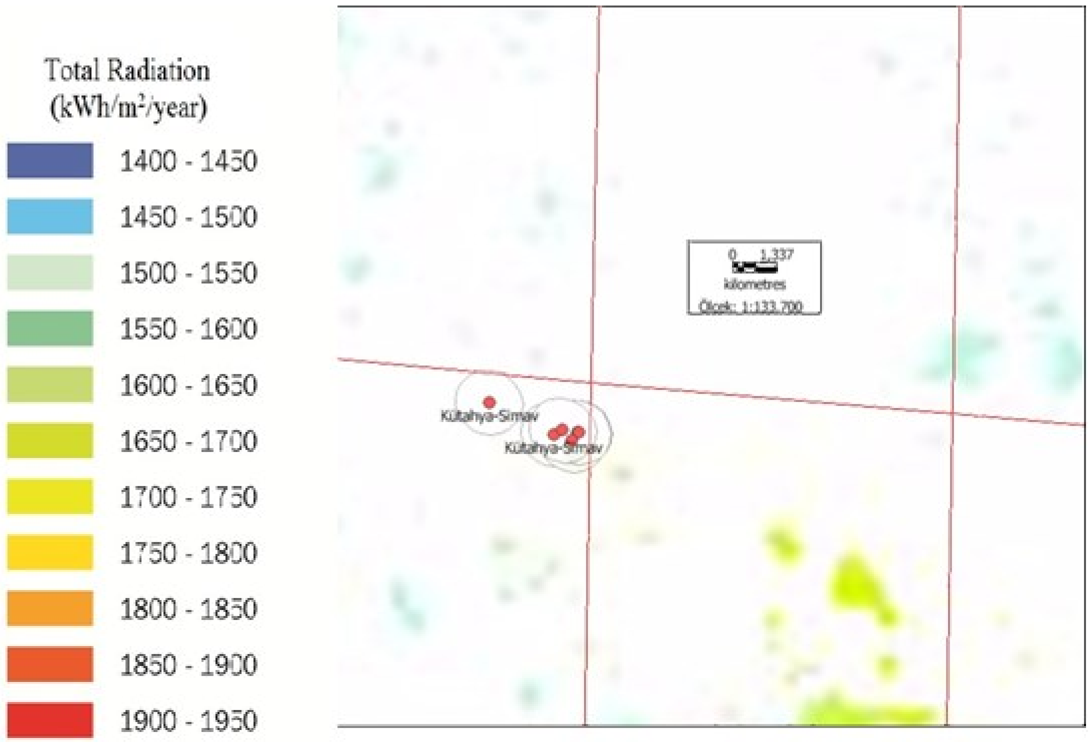

Figure 15: Map of usable lands (colored) intersected by buffer zones in Kütahya.

Manisa: Caferbey, Alaşehir and Emir geothermal sites are examined and none of them did catch any usable solar region.

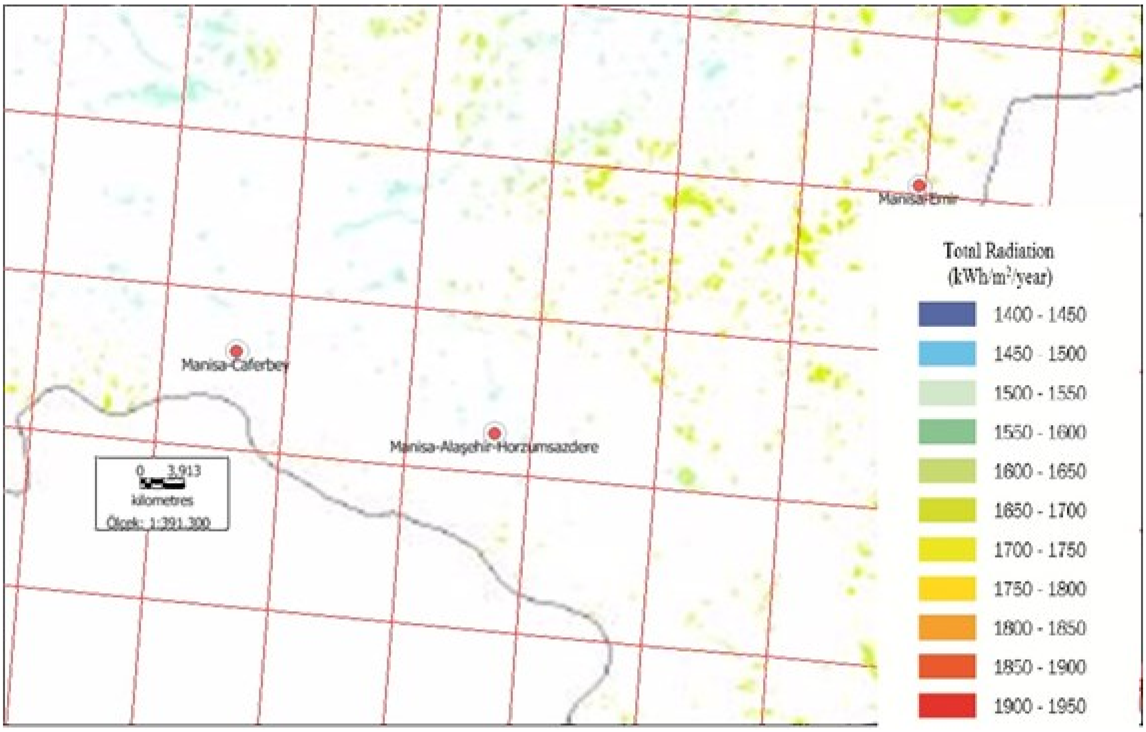

Figure 16: Map of usable lands (colored) intersected by buffer zones in Manisa.

Van: Here the examined geothermal area is called Erciş and it did not catch any usable solar area. Sunshine duration is already too low to facilitate solar energy in Van as discussed previously in Figure-10.

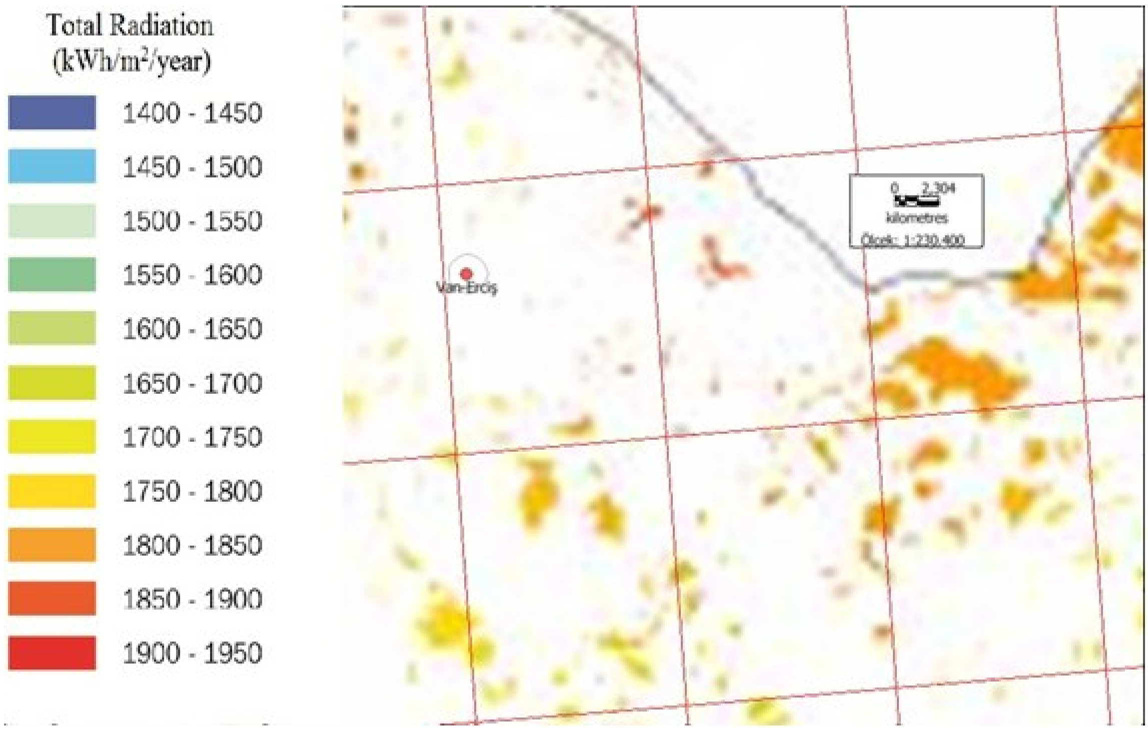

Figure 17: Map of usable lands (colored) intersected by buffer zones in Van.

Among Aydın, Çanakkale, Denizli, İzmir, Kütahya, and Manisa; Aydın was selected for a detailed analysis as there is more publicly available data for Aydın. Further, there are 57 geothermal spots , whose coordinates are known, which were used to make the map presented in Figure-7. Out of 57, 20 geothermal spots are in the city of Aydın and other 21 spots are in the vicinity of Aydın and Denizli cities, which shows that geothermal areas concentrate there.

3.3. General Information about City Aydın

Aydın is located on Turkey's western coast and has the geographic coordinates of 37°50′53″ N latitude and 27°50′43″E longitude. This city has good solar potential as seen in Figure-5, 6 and 7 and is rich in hot water resources. These geothermal fluids are being produced along the faults that form Büyükmenderes Graben.

There are 13 measurement stations of government that provide solar data in Turkey. Data is being interpolated for the other places. For this study, ambient temperature, sunshine duration and hourly diffuse and global solar radiation data, measured in Didim-Aydın station, was gathered from General Directorate of Renewable Energy.

Figure 18: Site location map of Turkey

3.4. Electrical Consumption Data of the Cities in Turkey

Figure-19 presents the electrical consumption data based on the cities. The regions where consumption increases are colored as darker red. Similar to Turkey, Aydın has an increasing energy demand. The electrical consumption of Aydın in 2002 was around 980296,843 MWh whereas it was 2087593 MWh in 2011 [22]. Based on low demand scenario created by TEİAS, the electrical consumption of Aydın is forecasted as 2655355,321 MWh for 2015 and as 3867254,905 MWh for 2021.

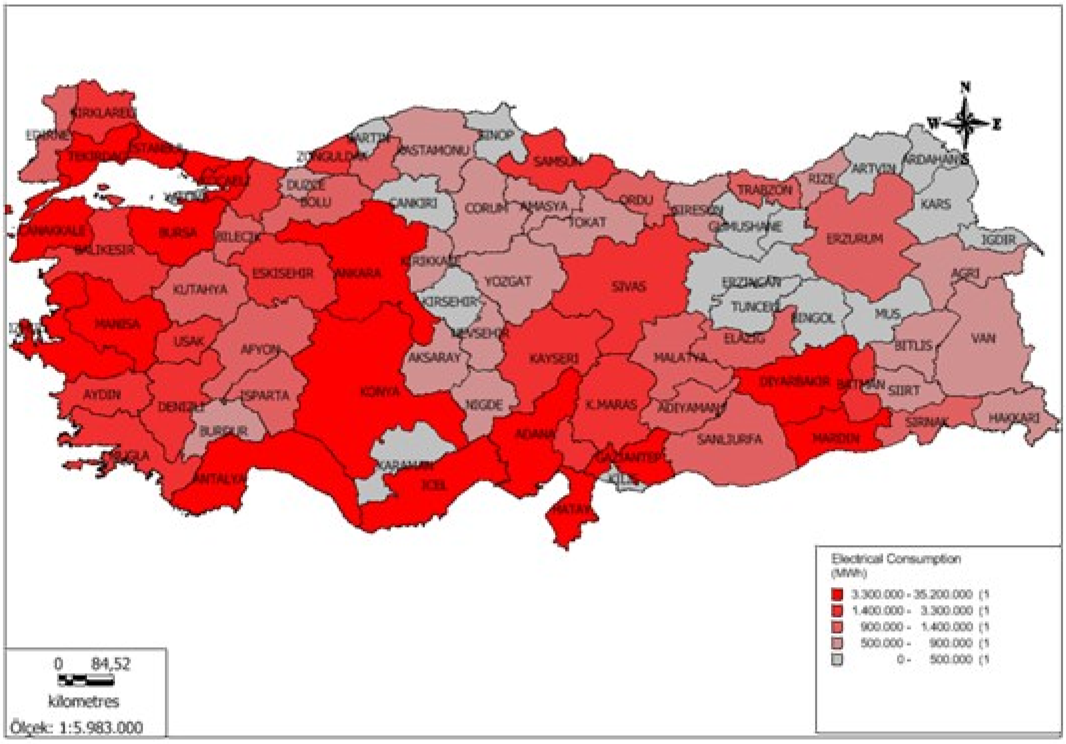

Figure 19: Map of electrical consumption based on cities in Turkey in 2011.

4. MODELING

For the analysis of the hybrid system, already taken part in literature, in terms of solar radiation and thermodynamics, Microsoft® Excel is used as a modeling tool. This part deals mostly with the efficiency of the hybrid system upon the generated power output when basic parameters such as temperature and pressure of geothermal fluid, organic working fluid type, direct solar radiation, type of parabolic trough, etc. change. System parameters, assumptions and the specifications are stated in detail in reference [14]. As mentioned earlier, hypothetical low enthalpy geothermal site in Aydın is analyzed as a case study.

5. DISCUSSION

As of October 2013, in Turkey, the number of the master thesis about geothermal is 177 in years 1991-2013 whereas there are 39 PhD thesis conducted in years 1993-2013. The number of the academic studies increased obviously when the energy sector started to draw more attention after 2005. Nevertheless, there are only 37 master studies about geothermal including not only electricity but also all the means of geothermal (such as isotope studies, geological structure of geothermal regions, economics, drilling technologies, greenhouse heating and etc.) published in the last 4 years [23]. Thus this study was a chance to summarize what has been done and to suggest what should be done in Turkish geothermal energy sector. On the other hand, to our knowledge, it is the first academic study that assesses the possibilities for combining geothermal and solar thermal power technologies in Turkey. In these manners, the findings of this research are promising.

5.1. Summary of the Results

In this study, assessment of possibilities for combining geothermal and solar thermal power technologies in Turkey was carried out. Its analysis was done for a hypothetical region in Menderes Graben.

Geothermal data was compiled mainly through the Inventory-201 published by MTA. Among more than 393 geothermal wells, ones with a temperature more than 100˚C were listed and mapped. Stated temperatures were assumed as well head and the other well characteristics were assumed as suitable for production. Considering the possibility of geothermal fluid transmission, buffer zones were assigned with a radius of 1 kilometer around the wells.

Solar data was compiled through GEPA. Regions that are suitable for solar power plant implementation were intersected by buffer zones. Each region was checked for its direct solar radiation value. Only Aydın-Söke region was found suitable for geothermal-solar hybrid plant.

Therefore, while western Anatolia is known as having potential for geothermal-solar hybrid plants, only Aydın-Söke region is found as suitable, which showed that these resources are not sharing common locations as much as expected.

An excel model was created to calculate power output of proposed hybrid system. Aydın was selected as a case study. Geothermal wells were assumed to produce at a temperature of 150˚C and with a flow rate of 100 kg/s. Hybrid system was composed of parabolic solar troughs, separator, air cooled condenser, circulation pumps, R134a as working fluid in the binary loop, heat exchangers, brine and steam turbines. Direct solar radiation, global solar radiation, sunshine duration and ambient temperature measurements were obtained hourly for year 2011 from Didim station in Aydın. Net power output was calculated as about 12 MW.

Previous work in this area focused on modeling the various hybrid configurations' thermodynamic performance. The present work extends this previous work by presenting maps that point potential regions suitable for this study in Turkey. Further, present work highlights the sustainability attributes of the discussed system as follows:

5.2. Critical Analysis of the System

Considering the fact that the main player in Turkish electricity production market is natural gas with a 31.9% share [24], the annual amount of saved carbon is calculated as around 15349 ton when 12 MWe is produced from geothermal-solar instead of natural gas.

Natural gas, which is mainly CH_4 i.e. Methane, combustion reaction with Oxygen is as follows:

$CH_4+2O_2 \rightarrow CO_2+2H_2O$

The molecular weight of methane is 12+ (4*1) =16 g

The molecular weight of CO_2 is 12+ (2*16) =44 g

It means that when 16 grams of natural gas is combusted, 44 grams of CO_2 is released to the atmosphere.

Here, the assumptions are;

• all the CO_2 released directly to atmosphere without any capture

• combustion of 1 m3 natural gas yields 8250 kcal energy [25]

• density of natural gas is equal to 0,7 kg/m^3 [26]

• 1 joule= 0,239 Cal

To convert 12 MW to kcal;

12*106 joules/sec *0,239 Cal/joules *10^{-3} kcal/Cal =2868 kcal/sec

To find the annual amount of saved carbon;

2868 kcal/sec* 60*60*24*365 year/sec =9,0445248 *1010 kcal in one year

To find the amount of natural gas which can supply that much of energy;

9,0445248 *1010 kcal / 8250 kcal/m^3 =10963060,36 m^3 natural gas

To find the mass of natural gas, the volume is multiplied by the density of natural gas:

10963060,36 m^3 *0,7 kg/m^3 = 7674142,252 kg CH_4

As shown previously, 16 g CH_4 yields 44 g CO_2

7674142,252 kg CH_4 yields 7674142,252 *44/16= 21103891,19 kg CO_2

If the efficiency of a natural gas cycle power plant is taken as 50%, then saved amount of CO_2 is doubled. It means that by using geothermal-solar rather than natural gas to generate 12 MW electricity, the annual amount of CO_2 saved is 42207782,38 kg. This fact highlights the sustainability attributes of the proposed system.

When it comes to the overburden on Turkish economy due to imported energy sources such as natural gas, generating 12 MWe from local geothermal-solar sources rather than imported natural gas saves around 11 million dollars.

As of 2012, considering that Turkey pays 505 dollars for 1000 m3 of natural gas to Iran and the efficiency of the plant is 50% again [27];

2*10963060,36 m3/1000 m3*505 $ =11072690,96 $

5.2.3. Suggestions for Future Investigation

This presented study is a starting point for future academic studies and for investors who plans to set up a business in geothermal-solar energy in Turkey. In the future with the required research and government promotion, these systems can be more popular and commercial. With the domestic equipment manufacturing, required project budgets may reduce. In developing nations such as Turkey, small scale clean energy plants can provide even larger benefits than large centralized power plants with job creation and less transmission loss [28]. Suggestions to improve the present study are as follows:

Considering the mapping part;

• Solar data that is used is based on the measurements of only 13 stations. For the accuracy of the data, the number of the measurement stations should be increased.

• The unusable lands map was in jpeg format and composed of 7 main constraints. A further detailed study can employ the vector map and form different layers by increasing the number the constraints. These additional constraints can be seismicity, proximity to transmission line corridor and water availability (water supply is necessary for wet cooling otherwise dry cooling option can be employed).

• Since the majority of the geothermal sites in Turkey are privatized, the current data is confidential and there is no access to it. That is why this study was conducted by employing the limited data which is not updated. There should be a national database not only for geothermal but also for other energy sources which is free for research purposes. It can increase the quality and enlarge the scope of the further research studies. Similarly if there is a national system providing disposal of the data, it can encourage the investors even in a not-win case.

• Since well characteristics are partly known, making an assumption across Turkey that states all of the used well data are suitable for production may introduce a large uncertainty into the results. A future study may calculate the concrete contribution of geothermal and solar thermal hybrid technology as a total power output throughout Turkey with all-known well characteristics.

Considering the model;

• The hybrid system examined in this thesis is not the only possible system that can combine geothermal and solar energy. Further studies may employ different hybrid configurations either with more emphasis on solar part or as an assist to already existing-power plants.

• In this model, heat storage was not included. It can be considered for the improvement of the model.

• In this study, solar thermal technology was employed. A further study may employ PV cells and compare the results.

• Air cooled condenser was employed in the model. A future study may employ wet cooled condenser and compare the results.

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