Comparison of the Effects of Regional Meteorological and Geographical Parameters on PV Generation Simulation Results

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Abstract: - Solar energy is a kind of renewable energy which should be given the most importance nowadays and will always be sustainable. It has a tendency to develop due to the awareness of consumable resources and environmental awareness. Nevertheless, solar energy is still lagging behind fossil-based energy production types. In this study, the simulation results of the two solar power plants in the Eastern Anatolian Region and the Black Sea Region are compared with the geographic and meteorological characteristics. In addition, real field conditions and analysis results are compared with 1-year data.

Key-Words: - Comparison, Solar Irradiation, Photovoltaic System, Energy Production, Geographical, Regional Differences

1 Introduction

The population of the world is increasing. In parallel with this, consumption in every field continues to increase day by day. One of the most important areas of consumption is energy sources. Also, energy needs are constantly increasing because of population growth, industrialization and development of infrastructure in Turkey and in the World [1].

In our world, energy sources are not unlimited. In this respect, used the fossil fuel sources for needed energy demand are rapidly depleted. Moreover, due to the negative effects of fossil fuel use, ambient temperatures rise on our planet, glaciers melt and natural disasters occur. In 2018, The world was 0.83^0 C warmer than the average set between 1951 and 1988 [2]. In addition, human, animal and plants are greatly damaged due to adverse effects of soil, water and air pollution. Due the fact that renewable energies that are clean, reliable and sustainable, which do not cause environmental problems for living beings are very important for future of human beings.

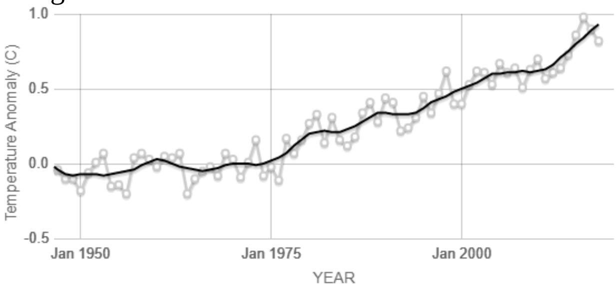

Fig. 1 Global Land-Ocean Temperature Index [2].

Renewable energy sources, either directly or indirectly, depend on the sun. There are different types of renewable energy such as wind, solar, hydrogen, ocean (tidal and wave), geothermal, biomass.

Solar energy is one the fastest growing and being most popular renewable energy type in the world. It is clean, sustainably and reliable energy type. It can be converted into electricity, heat and hot water.

There are two types of usage of solar panels. One of them is solar thermal panel which heats water, other one is photovoltaic solar panel that absorbs sunlight and change it to electricity energy via solar cells [3].

2 Solar Energy in the World and Turkey

The total amount of energy the world receives from the sun is 1.5 quadrillion MWh in a year. This amount of energy is equivalent to 28.000 times the energy consumed by people in the world in 1 year. According to the International Energy Agency (IEA), the sunlight that illuminates the earth for 90 minutes is enough to cover the annual energy needs of the whole world [4].

At the end of 2017, installed PV capacity reach to 404 GW. That was the 300 GW in 2016, 200 GW in 2015.

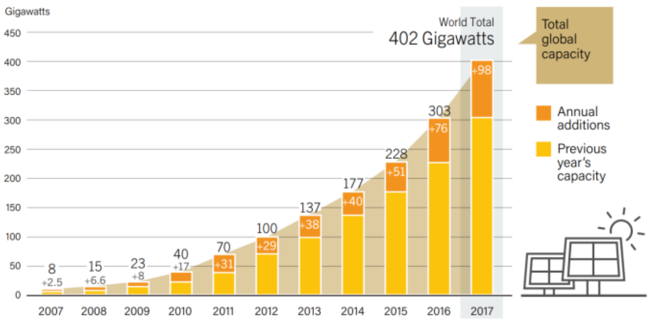

Fig. 2 Total installed PV Capacity [5].

Annual installed PV capacity was 76.6 GW in 2016 but it reached to 99.1 GW in 2017. After 2012, annual installed PV capacity increased every year [5].

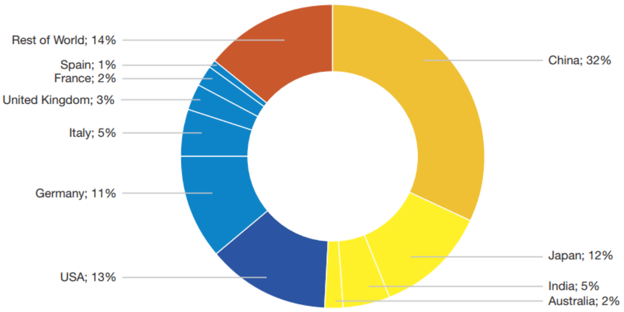

Fig. 3 Total installed PV shares by end of 2017 [6].

As it can be seen at Fig. 3 China is the biggest PV market in the world. China was trailed by the US and Japan. There is no European country at Top 3. Germany is fourth big market in the world [6].

As a result of developing production technologies, decrease in raw material prices and increase in cell efficiency, PV module prices decrease. It is 300 times cheaper than 40 years ago. While it was $ 76 per watt in 1977, it fell to $ 0.25 in 2017. Accordingly, thanks to various incentives and increased environmental awareness, the popularity and installed power of solar energy, which is most common renewable energy type nowadays, continues to increase day by day in the World [7].

With new investments and cost reduction of PV modules, it is expected that installed PV capacity could reach to over 1000 GW by end of the 2022 [6].

Turkey, lying in the sunny belt between 36° N and 42° N latitude, is located in a relatively advantageous geographical location for solar energy. Turkey's average annual total sunshine duration is calculated as 2737 h, and average total irradiation as 1527 kWh/m² a year.

Compared to other regions of Turkey, the Southeast Anatolia Region is the region with the most sun. This region is followed by the Mediterranean Region, the Eastern Anatolia region, the Central Anatolia region and the Aegean region. The Marmara Region is the region with less sunshine than the counted regions. The Black Sea region is the least beneficiary of solar energy compared to other regions. June is the sunniest month while December is the least month in Turkey [8].

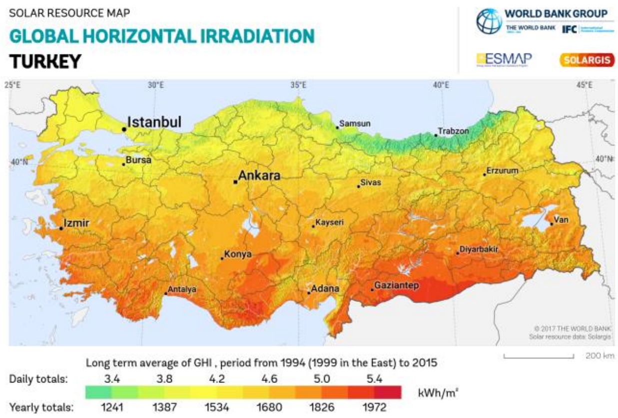

Fig. 4 Global Horizontal Irradiation in Turkey [9]

After China, USA, India and Japan; Turkey is the fifth biggest PV market in the world with 2.6 GW in 2017 and market leader for Europe.

TOP 10 COUNTRIES IN 2017			TOP 10 COUNTRIES IN 2017		
1	China	53 GW	1	China	131 GW
2	USA	10,6 GW	2	USA	51 GW
3	India	9,1 GW	3	Japan	49 GW
4	Japan	7 GW	4	Germany	42 GW
5	Turkey	2,6 GW	5	Italy	19,7 GW
6	Germany	1,8 GW	6	India	18,3 GW
7	Australia	1,25 GW	7	UK	12,7 GW
8	Korea	1,2 GW	8	France	8 GW
9	UK	0,9 GW	9	Australia	7,2 GW
10	Brazil	0,9 GW	10	Spain	5,6 GW

Fig.5 Top 10 Countries for installations and total installed capacity in 2017 [10]

According to National Renewable Energy Action Plan, Turkey's 2023 installed PV power target was 5 GW in 2014. It is started with 40 MW installed capacity in 2014, and increased to 208 MW in 2015, 832 MW in 2016, increased to 3420 MW in 2017 and at the end of 2018 total installed PV power reached to 5063 MW. Thus, Turkey hit its target before 5 years than expected. At the end of February 2019, cumulative PV installed capacity is 5.2 GW in Turkey [11,12].

In September 2017, new route map is announced by Turkish Ministry of Energy. New objective is 10 GW installed PV capacity until 2027 which is divided into 4000 MW for residential rooftops and 6000 MW for industrial and commercials systems [6].

With YEKA (Renewable Energy Resource Area) tender in March 2017, Turkey will be added 1 GW solar power plant into its PV capacity which brings 500 MW solar cell and module factory. For the tender, purchase guarantee is 15 years. It is expected that PV installed capacity will be 14 GW in 2023, and 38 GW in 2030 [5].

3 Regional Geographical and Meteorological Parameters

The most important part of a solar power plant is undoubtedly solar panels. Some conditions are necessary for high production of solar panels. When these conditions are met, the solar panel gives the highest power output. All investors target the highest production value in solar energy investments and therefore they expect the return on investment to be at the lowest level. According to the production analyzes of two different solar power plants in different geographies, the power plant that higher-output may not have shorter return of investment time. Not only high energy production, but also feed-in tariff warranties, purchase time warranties or subsidies provided by the purchasers or governments are extremely important for investments. However, while comparing the production values of two different solar power plants under the same economic conditions, geographic conditions and meteorological conditions where the power plants are located are highly significant.

Panel manufacturers emphasize panel powers while launching their products. However, this power output in standard test conditions (STC) that means cell temperature is 25 degrees, irradiance level is 1000 W / m^2 and air mass is AM1.5 obtained in laboratory conditions. These values can only be reached momentarily in real field conditions. Therefore, investors want to keep the AC output power at the highest level by using more panels as DC power.

The basis of photovoltaic energy production is based on the generation of current as a result of electron breakage of the radiation on the cell. The production of energy with radiation falling on the cell is directly proportional [13].

Shading is also a very important factor in radiation. The shadow on the panel causes the power output and efficiency drops. If the shading on the PV module is uniformly, all cells on the panel will be exposed to low radiation and as a result of this situation, power output decreases. However, in non-uniform shading cases, reverse current may occur because the cells that are shadowed by the shadows will act as loads. This situation can be caused hotspots. Such situations may not only cause the power output drop, but may also damage the panel. These situations should be avoided as much as possible [14].

Panel manufacturers share their power outputs according to different radiation values. Moreover, many factors such as cell efficiency, temperature, humidity, pressure, pollution and wind can affect energy production as distinct from radiation.

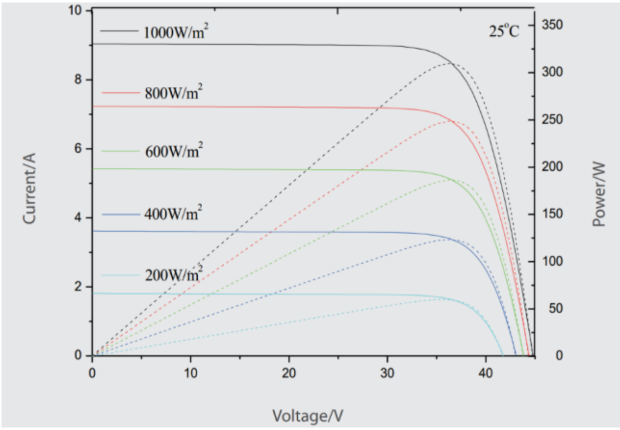

Fig. 6 Polycrystal PV irradiation-Power output relationship [15]

Energy efficiency in standard polycrystalline cells is around 14-20%, while amorphous solar panels are 7% CDTE panels 10-11% and CIGS panels are 20%. CIGS panels are quite expensive compared to polycrystalline panels. Under the same ambient conditions, panels with different characteristics can exhibit different behaviors [16].

Temperature is extremely important on panels. Since the panel surface is dark, they are exposed to a temperature of 20 degrees above the ambient temperature. This causes the efficiency of the panel to decrease during the hot summer days. Panel manufacturers publish temperature coefficients at their datasheets. These coefficients show how the temperature affects the panel and the efficiency of it. With the help of this coefficient, how the panel reacts to the temperature can be compared. Thin-film-based modules are less affected by temperature, whereas polycrystal-based modules are more affected.

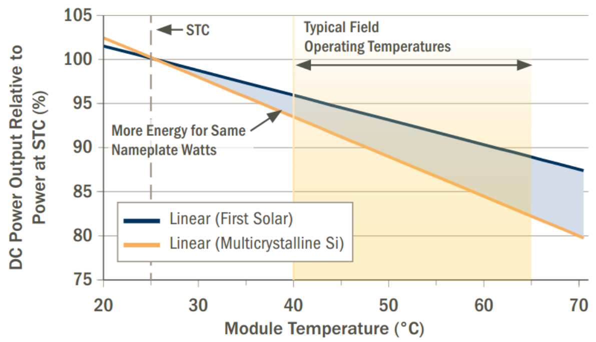

Fig. 7 Comparison of Temperature Effect on Thin Film and Polycrystal Panel Output [17]

Since the wind decreases the difference between the ambient temperature and the cell temperature, it has a positive effect on the panel performance. Due to the cooling of the cell surface, the temperature decreases indirectly and the power output increases.

Humidity is also very important for efficiency like temperature. Chaichan, Miqdam,'s study shows that when humidity increases, power output of module decreases [18].
For best production, sunlight should fall on the panel. However, due to dust or external factors, sunlight can't reach to module surface and it causes lower power output.

4 System Description

With these two identical projects, it can be seen effect of meteorological and geographical condition of The Eastern Anatolian region and The Black Sea region on solar energy production. Yesilkale project is in the Eastern Anatolian region. It closest to Sivas province border. Mesudiye is in the Black Sea region and it is in the north of Sivas province.

Fig.8 Project locations

Both projects' altitude is around 1300 m from sea level. They are located about at the same longitude which is 37.80 East. Yesilkale is located at 38.99 north latitude and 37.80 longitude, Mesudiye is located at 40.45 north latitude and 37.78 east longitude. As the crow flies, there is 160 km between two projects.
For the both solar power plants, it is assumed that project consist of 3672 pieces 310W 72 cell Polycrystalline PV module, 17 pieces 60 kW string inverter, fixed mounting system which is 4x9 PV module layout, 25^0 tilt angle, 7.50 m pitch length. Project's total DC power is 1138 kW, AC power is limited to 1000 kW due to the regularity of unlicensed power plants.
PVsyst v6.78 software which is trial version is used for energy yield analyses. It can be reached lots of meteorological data such as global horizontal irradiation, diffuse horizontal irradiation, average temperature etc. with this software and its databases. Also, it can be used for several loss inputs such as soiling, shading, Light Induced Degradation (LID), AC-DC losses, AC ohmic, Ohmic wiring etc. PVsyst has multifunctional features that can estimate P50, P90 probability outputs, self-consumption, economic model, several diagrams. It is a common software for solar energy sector [19].

Table 1. PV Module Specifications [15]

TYPE	JAP6 72-310/3BB
Rated Maximum Power at STC (W)	310
Open Circuit Voltage (Voc/V)	45.45
Maximum Power Voltage (Vmp/V)	37.00
Short Circuit Current (Isc/A)	8.85
Maximum Power Current (Imp/A)	8.38
Module Efficiency [%]	15.99
Power Tolerance (W)	-0~+5W
Temperature Coefficient of Isc (αIsc)	+0.058%/℃
Temperature Coefficient of Voc (βVoc)	-0.330%/℃
Temperature Coefficient of Pmax (γPmp)	-0.410%/℃

STC Irradiance 1000W/m^2, Cell Temperature 25℃, Air Mass 1.5

5 Results

Simulations are made with PVsyst v6.78 trial software which is the most prevalent program in the solar market.

Mesudiye_Project

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_User MWh	E_Solar MWh	E_Grid MWh	EFrGrid MWh
January	54.0	25.41	-3.43	83.1	73.6	84.3	0.510	-0.339	81.7	0.849
February	71.5	34.15	-1.91	96.8	88.5	100.8	0.460	-0.261	97.7	0.721
March	106.9	47.52	4.46	126.3	116.2	125.9	0.510	-0.224	122.1	0.734
April	129.1	71.35	9.55	137.4	125.5	135.1	0.493	-0.131	131.1	0.624
May	149.3	84.24	14.08	148.4	134.7	142.9	0.510	-0.093	138.7	0.603
June	178.0	76.51	17.89	172.1	157.4	162.2	0.493	-0.032	157.5	0.525
July	184.9	82.45	21.98	182.2	166.7	168.5	0.510	-0.070	163.7	0.579
August	169.4	59.42	22.27	177.1	163.1	163.7	0.510	-0.107	159.1	0.617
September	128.9	51.12	17.09	149.9	138.4	142.1	0.493	-0.180	138.0	0.673
October	87.9	39.46	12.07	114.0	104.7	111.2	0.510	-0.260	107.9	0.770
November	48.9	27.56	4.89	68.2	61.1	67.6	0.493	-0.322	65.4	0.815
December	44.5	22.55	-1.01	69.1	60.3	68.5	0.510	-0.368	66.3	0.878
Year	1353.3	621.74	9.89	1524.5	1390.0	1472.9	6.001	-2.388	1429.1	8.389

Legends:
GlobHor Horizontal global irradiation
DiffHor Horizontal diffuse irradiation
T_Amb Ambient Temperature
GlobInc Global incident in coll. plane
GlobEff Effective Global, corr. for IAM and shadings
EArray Effective energy at the output of the array
E_User Energy supplied to the user
E_Solar Energy from the sun
E_Grid Energy injected into grid

Fig. 9 Main results for Mesudiye Project

As it can be seen Fig. 10 global horizontal irradiance for annual is 1353.3 kWh/m^2, horizontal diffuse irradiation is 621.74 kWh/ m^2 , average temperature is 9.89^0 C, global incident in collapse plane that means irradiation to panel surface according to tilt angle is 1524.5 kWh/ m^2, after shading and Incidence Angle Modifier (IAM), global incidence drops to 1390 kWh/ m^2, after the calculations effective energy at the output of array is 1472.9 MWh and finally after inverter, self-consumption, AC wiring and transformer loss energy injected into grid is 1429.1 MWh.
The most production is in July, the least production is in November. Although irradiance in November higher than December, energy production in November is lower than December. Since it is considered global incident in collapse plane after

than IAM and shading effects, global effective irradiation of November is 61.1 kWh/ m^2, but global effective irradiation of December is 60.3 kWh/ m^2. Despite all this, December has approximately 5 Celsius degree lower temperature than November, as a result of this, energy yield of December is higher than November. It can be seen clearly temperature effect on solar energy production.

Yesilkale_Project

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_User MWh	E_Solar MWh	E_Grid MWh	EFrGrid MWh
January	58.0	29.37	-3.37	85.6	76.7	88.1	0.510	-0.343	85.4	0.853
February	76.4	36.66	-1.82	100.8	92.4	105.0	0.460	-0.261	101.8	0.721
March	117.8	56.33	4.55	140.2	128.9	141.7	0.510	-0.217	137.5	0.727
April	144.4	71.51	9.62	153.6	140.7	150.3	0.493	-0.138	145.9	0.631
May	172.6	84.45	14.17	171.5	156.6	164.7	0.510	-0.102	160.0	0.612
June	203.6	74.27	18.16	196.1	180.1	184.6	0.493	-0.029	179.2	0.522
July	216.3	69.62	22.17	212.3	195.4	196.3	0.510	-0.070	190.7	0.579
August	200.7	59.37	22.49	211.5	195.6	195.7	0.510	-0.107	190.2	0.617
September	156.9	50.36	17.26	185.9	172.3	176.7	0.493	-0.176	171.7	0.669
October	108.6	43.42	12.12	142.2	131.1	138.9	0.510	-0.250	134.9	0.759
November	66.0	30.48	5.01	95.4	86.4	95.1	0.493	-0.309	92.2	0.802
December	51.5	22.95	-0.87	80.8	71.1	80.5	0.510	-0.345	78.0	0.855
Year	1573.0	628.80	10.03	1776.0	1627.2	1717.7	6.001	-2.347	1667.6	8.347

Legends:
GlobHor Horizontal global irradiation
DiffHor Horizontal diffuse irradiation
T_Amb Ambient Temperature
GlobInc Global incident in coll. plane
GlobEff Effective Global, corr. for IAM and shadings
EArray Effective energy at the output of the array
E_User Energy supplied to the user
E_Solar Energy from the sun
E_Grid Energy injected into grid
EFrGrid Energy from the grid

Fig. 10 Main results for Yesilkale Project

As it can be seen Fig. 11 global horizontal irradiance for annual is 1573 kWh/m^2, horizontal diffuse irradiation is 628.80 kWh/ m^2 , average temperature is 10.03^0 C, global incident in collapse plane is 1776 kWh/ m^2, global incidence is 1627.2 kWh/ m^2, after the calculations effective energy at the output of array is 1717.7 MWh and finally after inverter, self-consumption, AC wiring and transformer loss energy injected into grid is 1667.6 MWh.

The most production is in July same as Mesudiye project, but the least production is in December at Yesilkale. Difference irradiation level between November and December months is clearly higher than Mesudiye project. Although temperature effect is in favor of November, irradiance effect is more powerful. That's why, energy output in December is lower than November.

If it is compared Mesudiye and Yesilkale projects, it is obviously seen that, Yesilkale has more irradiance than Mesudiye due to its geographical place while annual average temperature is nearly same. The least difference between global effective irradiation is in January and the most difference is in September. One of the most important reason of less irradiance at Mesudiye project is more cloudy days according to Yesilkale thanks to Black Sea Climate. Black Sea Climate also brings more humidity that is inversely proportional with energy production. When the energy yield results are examined, as expected, the least energy yield difference between two projects is in January which is 3.7 MWh, while the most difference is in September which is 33.7 MWh.

When the radiations of these two projects are compared, it is observed that Yeşilkale is exposed to 16.23% higher horizontal radiation, 16.49% more incident radiation, 17.06% more effective radiation. It can be said that 16.62% more energy is produced in arrays and 16.69% more energy is produced annually.

In addition to this approaches, real production result from Yesilkale Solar Power Plant supports ideas that inferenced in this study. Energy production in December is the least, July is the most.

When it is compared annual energy production with real results and PVsyst analyses, simulation software bias only %2 that is really good result. The most difference between real results and simulation expectations in monthly is December, the least is November. In April, 23% more energy was produced than expected, in December %56 less energy produced than expected. These differences may have been caused by changing climatic conditions. In order to better understand matching analysis and real results, it is required a few years of data.

Table 2. Real energy production results against the simulation results of Yesilkale Project

Month	Year	Real Results	PVsyst	Difference
January	2018	73.830,76 kWh	85.400,00 kWh	-14%
February	2018	102.423,35 kWh	101.800,00 kWh	1%
March	2018	119.703,24 kWh	137.500,00 kWh	-13%
April	2018	178.810,18 kWh	145.900,00 kWh	23%
May	2018	163.591,28 kWh	160.000,00 kWh	2%
June	2018	180.955,48 kWh	179.200,00 kWh	1%
July	2018	213.193,41 kWh	190.700,00 kWh	12%
August	2018	207.633,58 kWh	190.200,00 kWh	9%
September	2018	177.642,53 kWh	171.700,00 kWh	3%
October	2018	142.312,87 kWh	134.900,00 kWh	5%
November	2018	91.844,98 kWh	92.200,00 kWh	0%
December	2018	43.351,23 kWh	78.000,00 kWh	-56%
Total		1.695.292,89 kWh	1.665.000,00 kWh	2%

6 Conclusion

In this study, energy production simulations of two identical solar power plants in two different regions are compared. This comparison is made with PVsyst software which is the most widely usage in the solar market.

Results of the software are compared with the real production data of the solar power plant which installed in Yesilkale for 1 year. When the total annual results are examined, it is seen that there is 2% difference between real production and simulated result. Also, there is 1% difference as the monthly deviation.

Considering the differences between the two regions on the same longitude, it is seen that the meteorological results caused by climate and geographical differences are very important in solar energy production. It is determined that, in spite of the fact that there is 160 km distance between two projects, factors such as cloudy days, radiation, temperature and humidity can affect energy production around 17%.

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