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RESEARCH ARTICLE / ARAŞTIRMA MAKALESİ

Solar Power Plant Efficiency and Economically Analysis in Different Regional Climate for Selected Cities in Turkey

Türkiye'nin Farklı İklim Bölgelerinden Seçilmiş Bazı İllerin Güneş Enerji Santrali Verimliliklerinin İncelenmesi ve Ekonomik Analizi

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Abstract
Solar power plants are one of the increasingly important energy production facilities with clean and renewable properties. In this context, an advanced solar power plant is the one that includes panels operating on the basis of photovoltaic principle. In this study, performance ratio as part of energy efficiency of photovoltaic solar power plants of Istanbul, Konya, Van and Ordu provinces in different regions were analyzed and economics analyzes were performed. The facilities located in different climatic regions were evaluated comparatively. Considering the increase in investments in the renewable energy sector, the efficiency evaluation of solar power plants will be a useful study both in terms of scientific and economic efficiency of investments. In this study, the design and analysis of 1 MW solar power plants were performed with PVsyst software. As a result, the annual power plant performance ratio is %87.52 in Istanbul, %86.97 in Konya, %87.19 in Van, and %88.14 in Ordu. According to the average electricity unit price in Turkey, the installation cost of a power plant with an installed power of 1 MWe was found to be 616,270 $. The depreciation period was found to be 4.54 years in Istanbul, 3.47 years in Konya, 3.67 years in Van, and 5.1 years in Ordu. Also, energy efficiency and economic analysis were completed.
Keywords: Solar power plant, Photovoltaic, PVsyst, economical analysis, comparison of different regions.

Öz
Güneş enerjisi santralleri temiz ve yenilenebilir özellikleri nedeniyle önemi giderek artan enerji üretim tesislerinden biri durumundadır. Gelişmiş güneş enerjisi santrali, fotovoltaik prensibine göre çalışan panelleri içeren bir santraldir. Bu çalışmada İstanbul, Konya, Van ve Ordu illerinin farklı bölgelerinde bulunan fotovoltaik güneş enerjisi santrallerinin enerji verimliliği bağlamında performans oranları analiz edilmiş ve ekonomik analizleri yapılmıştır. Farklı iklim bölgelerinde yer alan tesisler karşılaştırmalı olarak değerlendirilmiştir. Yenilenebilir enerji sektöründeki yatırımların artması göz önünde bulundurulduğunda, güneş enerjisi santrallerinin verimlilik değerlendirmesinin yapılması, yatırımların hem bilimsel hem de ekonomik verimliliği açısından faydalı bir çalışma olacaktır. Bu çalışmada 1 MW'lık güneş enerjisi santrallerinin tasarımı ve analizi, PVsyst yazılımı ile gerçekleştirilmiştir. Çalışmanın sonucunda; yıllık performans verimi İstanbul için %87,52; Konya'da %86,97; Van'da %87,19 ve Ordu'da %88,14 olarak bulunmuştur. Türkiye'deki birim elektrik fiyatına bağlı olarak; 1 MWe kurulu güçteki santral için kurulum maliyeti 616,270 $ olarak hesaplanmıştır. Geri ödeme süresi İstanbul için 4,54 yıl, Konya için 3,47 yıl, Van için 3,67 yıl ve Ordu için 5,1 yıl olmaktadır. Böylece enerji verimliliği ve ekonomik analizler tamamlanmıştır.
Anahtar Kelimeler: Güneş enerjisi santrali, Fotovoltaik, PVsyst, ekonomik analiz, farklı şehirlerin karşılaştırılması.

I. INTRODUCTION

Energy needs are increasing day by day in parallel with living conditions in society and developments in the industry. Two types of sources are used to meet the energy need, namely non-renewable energies and renewable energies. With the use of fossil fuels, which are non-renewable energy sources, carbon emissions and greenhouse gas emissions increase [1]. For this reason, fossil fuel power generation directly affect the ecosystem and human life. Beside, since fossil fuel reserves are limited and decreasing, the demand for renewable energy sources has increased as an alternative to fossil fuels. Among the renewable energy sources, the most important one in terms of cost and efficiency is solar energy [2-6].

Turkey is one of the most remarkable locations in the world in terms of solar energy potential. Annual and daily sunshine duration is way above the world average. In Turkey annual average solar radiation is 1303 kWh/m² year, and the average annual sunshine duration is 2623 hours. This figure corresponds to 3.6 kWh/m²-day

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energy, approximately 7.2 hours/day, and annually 110 days of sunshine. In other words, there is a potential of 26.2 million toe per year [7].

Turkey can benefit of solar energy from 63% of the country's surface area technically and economically in 10 months of the year and 17% throughout the year. Investment and R&D activities for solar energy in Turkey have increased significantly since 2013. With the significant increase in investments in Turkey, researches on issues such as efficiency and optimization have started. Many variables such as sunshine duration, radiation angles, temperature, humidity, wind, location (detailed coordinates), panel type and inverter efficiency are investigated in detail by R&D companies and universities [8-11].

While planning solar energy application, regional climatic differences in Turkey are generally not taken into account. In this study, one province was selected from the regions showing different climate characteristics, and solar power plants suitable for those provinces were designed and their efficiency was examined. Purpose of the study; to assist in the planning of future energy investments by making a comparative evaluation of solar power plants under different climatic conditions. Since this will guide the investor, it will contribute to a more accurate planning and project design. Efficiency evaluations have been made in different countries by taking into account the climatic conditions, but there is not enough work in this field in our country. With this study, it is aimed to make an important contribution to the missing interregional SPP efficiency studies.

In this study, performance ratio (PR) as part of energy efficiency was calculated and economic analysis was carried out with the same capacity solar power plant project in Istanbul, Konya, Van and Ordu provinces which each of the cities located in 4 different climate zones. PR calculations were made for each climate zone separately. According to these calculations, ideal SPP elements were selected. After the selection process, the calculation of the SPP cost according to each climatic region and the interregional differences were found. In line with the aims and objectives stated in the study, the PVsyst program was used. With this program, hourly, daily and monthly sunshine durations, solar radiation and radiation values between regions were determined. The solar maps of the selected provinces are shown in Figure 1.

In the study, an economic comparison was made by designing a solar power plant with an installed power of 1 MWe in the selected provinces and taking into account the energy efficiency of the facilities with the same capacity among the regions.

II. MATERIAL AND METHODS

PVSyst software was used to design the solar power plant. In the software, the exact coordinates of the selected provinces were inputted the radiation values, average temperature, wind speed and humidity values were found. The latitude and longitude values of the selected provinces are shown in Table 1. According to these data, photovoltaic panels and inverters, which are the main power plant elements, were selected and their numbers and details were determined according to these selections. At the end of the design, the monthly energy production data of the power plant with an installed power of 1 MWe in each province and the average PR of the facility were also calculated. PR is calculated by formula;

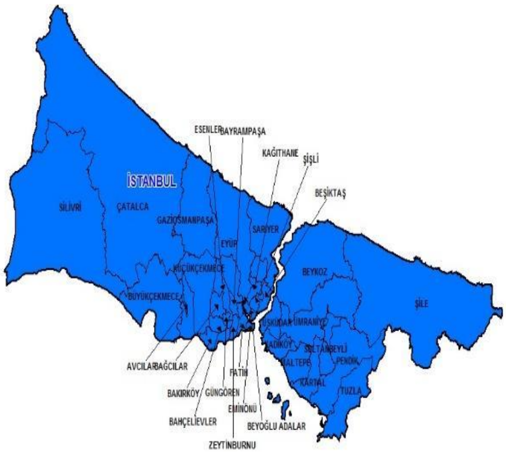
$$PR = E_{grid} \big/ G_{inc} \cdot P_{nom}$$

Where E_{grid} is the available energy, G_{inc} is the global incident, and P_{nom} is the standard conditions installed power.

In this study, to compare the performance of power plants considered for the regions, SPP elements were accepted with the same capacity. In order to make a correct comparison, the number of panels connected in series was determined as the same number of PV panels installed at the same angle of inclination in each project.

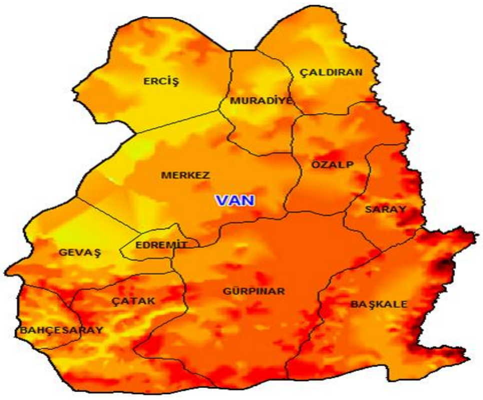
Table 1. Coordinates of selected provinces

Province	Latitude (North)	Longitude (East)
Istanbul	41.01384	28.94966
Konya	37.87135	32.48464
Van	38.6909	43.2957
Ordu	40.9706	37.8822

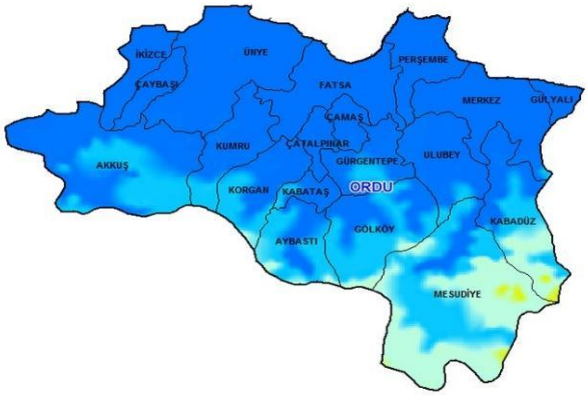


a) Istanbul

b) Konya



c) Van



d) Ordu

Figure 1. Solar energy maps of provinces a) Istanbul, b) Konya, c) Van, d) Ordu [12].

2.1. Design of solar power plant

In solar power plant design, in order to obtain the maximum efficiency of 12 months, the panel tilt angle and azimuth value must be entered first. The software can determine the most suitable panel inclination angle and azimuth angle by creating scenarios according to different angles considering seasonal differences according to the selected location. The appropriate inclination angle and azimuth value determined by the software as a result of the rapid scenario creation method in terms of Turkey's location are shown in Table 2.

Table 2. Orientation of PV array

Tilt angle	30°
Azimuth	0°

In the continuation of the design, panel and inverter selection will be made. In this study, Canadian Solar was chosen as the panel and Fronius brand was chosen as the inverter. The technical specifications of these selected switchboard elements are shown in Table 3 and Table 4 [13,14].

Table 3. Technical data of Canadian Solar Module

Specification	Data
Cell type	Mono-crystalline
Dimensions	1650×992×40 mm
Nominal Max. Power	280W
Optimum Operating Voltage	31.5V
Optimum Operating Current	8.89A
Open Circuit Voltage	38.5V
Short Circuit Current	9.43A
Temperature Coefficient (at max. power)	-0,41% / °C
Module Efficiency	17,11%

Table 4. Technical data of Fronius Inverter

Specification	Data
Number of MPP trackers	1
Max. input current	47,7 A
Max. short circuit current	71,6 A
DC input voltage range	580-1000 V
Feed-in start voltage	650 V
Nominal input voltage	580 V
MPP voltage range	580-850 V
Usable voltage range	580-850 V
Number of DC connections	6
Max. PV generator power	37,8 kW-peak

The common design details of the power plant designed for each province are shown in Table 5.

Table 5. Design details

Installed capacity (kWe)	1000
Inverter (kW)	25
Number of inverters	37
Number of strings	5
Number of arrays	23
Number of modules/Inverter	115
Total number of modules	4255
Module power (kW)	265
Total peak power (Wp)	1127575
Total peak power (kWp)	1127,575

III. RESULTS AND DISCUSSION

3.1 Energy analysis

In Istanbul, Konya, Van and Ordu, the radiation, ambient temperature, loads, energy coming out of the PV system, energy supplied to the grid and power plant performance ratio in these regions were obtained by projecting with PVSyst software. The distribution of the data obtained from the power plants by months is shown in Table 6, Table 7, Table 8 and Table 9 for 4 provinces.

The data obtained from four different regions are shown in Figure 2 and Figure 3 graphically, comparing energy production data and power plant efficiencies. Annual total energy production and power plant PR of the plants are shown in Table 10.

Table 6. Data obtained in the province of Istanbul

	Horizontal Irradiance kWh/m²	Vertical Irradiance kWh/m²	Ambient temperature °C	Global incident kWh/m²	Effective global incident kWh/m²	Effective produced energy MWh	Energy injected into grid MWh	PR
January	46.2	24.46	6.25	70.8	69.6	80.8	78.9	0.935
February	57.7	32.86	6.27	75	73.7	84.4	82.4	0.922
March	96.5	46.85	8.96	117.30	115.1	129.3	126.4	0.905
April	134.6	72.27	12.32	144.5	141.3	157.1	153.6	0.893
May	175.2	76.37	17.78	172.4	168.7	181.5	177.6	0.865
June	187.3	91.28	22.37	178.2	174.2	185.5	181.6	0.855
July	194.3	83.09	25.59	187.3	183.2	190.9	186.9	0.838
August	167.7	74.08	25.54	177.2	173.5	180.5	176.8	0.837
September	128	53.7	20.93	150.7	147.8	156.6	153.3	0.854
October	87.3	49.37	17.05	112.5	110.3	122.3	119.6	0.892
November	55.4	30.14	11.93	81.8	80.3	90.9	88.9	0.912
December	41.7	25.87	8.25	63.2	62	72.1	70.4	0.935
Annual	**1371.9**	**660.35**	**15.33**	**1530.7**	**1499.6**	**1632**	**1596.2**	**0.875**

Table 7. Data obtained in the province of Konya

	Horizontal Irradiance kWh/m²	**Vertical Irradiance kWh/m²**	**Ambient temperature °C**	**Global incident kWh/m²**	**Effective global incident kWh/m²**	**Effective produced energy MWh**	**Energy injected into grid MWh**	**PR**
January	70.4	28.2	-0.70	110.8	109.2	128	125	0.947
February	89.1	36.1	1	126.4	124.4	144.9	141.7	0.941
March	136.5	53.2	6.5	167.10	164.1	181	177	0.889
April	159.3	73.5	11	168.2	164.7	179.3	175.4	0.875
May	204.1	76	16.3	199.3	195	208.5	204	0.859
June	224	62.8	21	208.4	203.9	212.7	208.3	0.839
July	236.7	58.1	24.9	224.5	219.8	224.2	219.6	0.821
August	215.1	52.5	24.3	225.6	221.2	225.4	220.8	0.822
September	165.4	50.1	18.6	194.9	191.3	199.7	195.6	0.842
October	119.5	41.1	13.3	161.3	158.8	172	168.3	0.876
November	79.3	28.9	6.1	122.4	120.6	135.8	132.8	0.91
December	61.7	23.8	1.1	105.2	103.5	121.4	118.6	0.947
Annual	**1761.1**	**584.3**	**12.02**	**2014.2**	**1976.5**	**2133**	**2087**	**0.87**

Table 8. Data obtained in the province of Van

	Horizontal Irradiance kWh/m²	**Vertical Irradiance kWh/m²**	**Ambient temperature °C**	**Global incident kWh/m²**	**Effective global incident kWh/m²**	**Effective produced energy MWh**	**Energy injected into grid MWh**	**PR**
January	61.7	30.99	-2.23	93.6	92	109.7	107.1	0.961
February	79.3	46.75	2.74	103.4	101.6	118.9	116.2	0.944
March	117.3	71.86	8.97	136.50	133.9	152	148.7	0.914
April	153	79.82	13.72	164.6	161.3	177.5	173.6	0.885
May	198.8	85.03	18.47	196.3	192.3	205.5	201.1	0.86
June	218	85.77	23.31	207.1	202.8	211.5	207.2	0.84
July	221.5	86.45	26.76	214.8	210.4	215.5	211.2	0.825
August	209.7	67.8	26.86	222	217.9	220.8	216.3	0.818
September	169.5	49.48	21.69	203.8	200.3	207.8	203.5	0.838
October	117.6	48	15.67	157.7	155.2	168.7	165.1	0.879
November	75.9	36.92	7.73	113.4	111.6	127.8	125	0.925
December	55.1	31.22	1.08	84.3	82.8	98.3	96.1	0.956
Annual	**1677.4**	**720.1**	**13.79**	**1897.6**	**1862.1**	**2014.1**	**1971.2**	**0.872**

Table 9. Data obtained in the province of Ordu

	Horizontal Irradiance kWh/m²	Vertical Irradiance kWh/m²	Ambient temperature °C	Global incident kWh/m²	Effective global incident kWh/m²	Effective produced energy MWh	Energy injected into grid MWh	PR
January	48.5	24.6	6.41	76	74.7	86.3	84.3	0.931
February	62.4	33.4	6.58	83.2	81.8	93.8	91.6	0.924
March	94.6	50.32	8.87	110.20	108.1	121.2	118.3	0.901
April	117.9	73.7	11.15	124.2	121.5	136.6	133.5	0.902
May	151.3	87.7	15.66	148.3	144.7	159.1	155.6	0.881
June	164	82	20.04	156.7	153.1	163.9	160.4	0.859
July	153.1	78	23.78	146.8	143.3	150.9	147.6	0.844
August	138.8	81.37	24.43	141.4	138.1	146.4	143.2	0.85
September	110	61.64	20.6	124.8	122.3	131.1	128.2	0.862
October	78.6	40.08	17.06	100.3	98.5	106.7	104.3	0.873
November	50.3	27.05	11.85	74.3	73	82.1	80.2	0.905
December	43.3	23.6	8.22	69	67.7	77.9	76.1	0.925
Annual	**1212.7**	**663.47**	**14.61**	**1355.3**	**1326.9**	**1455.9**	**1423.2**	**0.881**

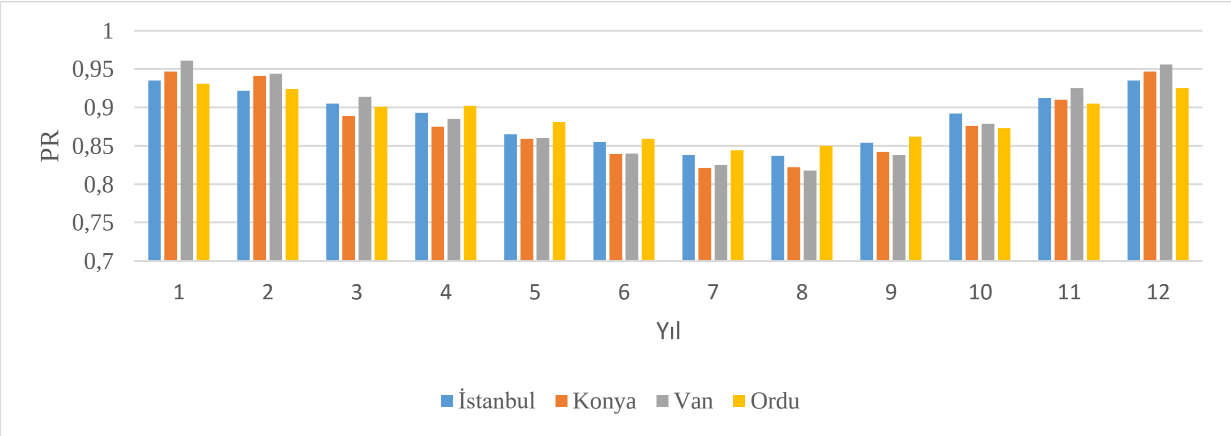


Figure 2. Monthly power plant PR by province

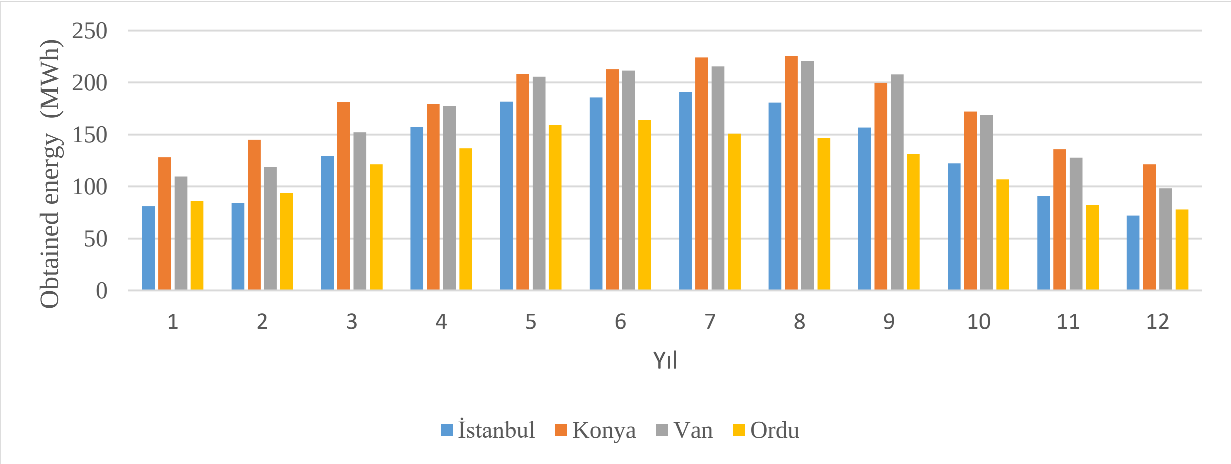


Figure 3. Monthly energy obtained by provinces (MWh)

Table 10. Annual electricity production and power plant PR

	MWh/year	**Power plant PR**
Istanbul	1596	87.52%
Konya	2087	86.97%
Van	1971	87.19%
Ordu	1423	88.14%

3.2 Economic analysis

Since the solar power plants in four different provinces are planned with the same capacity, system elements and other processes will be the same. Because of this situation, it will be sufficient to make a single cost feasibility.

The requirements for cost analysis and their unit element costs and total costs are shown in Table 11. With this analysis, the power plant installation cost was calculated as $616.270.00.

Table 11. Cost analysis

	Unit cost ($)	Total cost($)
PV module (Wp)	0.28	338,800
Construction (Wp)	0.07	85,470
DC-AC Cable		20,000
Inverter	2,000.00	74,000
AC panel	5,000.00	5,000
Transformer	25,000.00	25,000
Power transmission line	20,000.00	20,000
Ground	3,000.00	3,000
Wire fence, cameras	15,000.00	15,000
Field leveling, transport	30,000.00	30,000
Power plant installation		616,270

For the economic analysis, the income calculation was made depending on the annual electricity values produced by the power plants, taking into account the electricity market clearing price, and the annual income values are shown in Table 12. With these data, amortization periods were calculated and shown in Table 13.

Table 12. Annual income estimation

	Electricty generation (mWh/year)	Electricity market clearing price ($)	Annual earnings ($)
Istanbul	1596	85.00	135,660.00
Konya	2087		177,395.00
Van	1971		167,535.00
Ordu	1423		120,955.00

Table 13. Depreciation time

Istanbul	4.54
Konya	3.47
Van	3.67
Ordu	5.1

IV. CONCLUSION

Solar power plant projects were carried out in the provinces of Istanbul, Konya, Van and Ordu located in different regions. With this project, meteorological data were obtained by using the PVsyst software, and then the panel and inverter, which are the main solar power plant elements, were selected.

Comparative results of energy production data and efficiencies in each province are shown graphically with the PVsyst software. In the continuation of the study, the installation cost of a facility with an installed power of 1 mWe was calculated by calculating the power plant elements and all other expenses.

As a result, with the projects carried out in the provinces of Istanbul, Konya, Van and Ordu, it is expected to produce 1596 mWh electricity per year in Istanbul, 2087 mWh per year in Konya, 1971 mWh per year in Van and 1423 mWh in Ordu.

The average electricity unit price in Turkey in 2018 and 2019 is approximately $85/mWh. The installation cost of a power plant with an installed power of 1 MWe was found to be 616,270.00 $.

As a result, annual income will be $135,660.00 in Istanbul, $177,395.00 in Konya, and $167,535.00 in Van. In the framework of these data, the depreciation period in a power plant established with 100% capital was found to be 4.54 years in Istanbul, 3.47 years in Konya, 3.67 years in Van, and 5.1 years in Ordu.

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