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Original scientific paper

Technoeconomic Analysis of 1 MWp Grid Connected Solar Power Plant in Konya (Türkiye)

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Abstract: Global warming is seen as one of the most important problems that trigger climate change in the world. The leading cause of global warming is the high amount of greenhouse gases released into the atmosphere. Countries are creating policies to encourage the use of renewable energy sources to control greenhouse gas emissions. Many universities in Türkiye have enough campus areas to generate electricity from renewable energy sources. The main purpose of this article is to analyze the feasibility of developing a solar power plant at Necmettin Erbakan University. This article proposes a 1MW solar power plant in Necmettin Erbakan University Köyceğiz Campus located in the city of Konya, which has the largest surface area in Türkiye. The technical feasibility of the proposed PV plant was analyzed using PVGIS, PVWatts, and PVsyst software. For this purpose, the economic and environmental aspects of the power plant to be established on campus were investigated through the production data. 1 MWp solar power plant can generate approximately 1685.78 MWh of electricity per year while reducing 820.21 tCO_2 greenhouse gas emissions. The technical data obtained in the analyses made with PVGIS, PVWatts, and PVsyst software are similar.

Keywords: cost; electricity generation; financial analysis; solar panel

1 INTRODUCTION

The global demand for energy consumption is increasing by the day. Some of this demand is met by fossil fuels, but fossil fuel resources are rapidly depleting [1]. However, the negative effects of fossil fuels on the environment are triggered by climate change. There are clean, reliable and sustainable renewable energy sources that human beings can use against these negative situations. These energy sources play an important role both for the future of humankind and for reducing foreign dependency of countries [2-4].

The sun is the universe's primary source of energy. It is one of nature's cleanest and most inexhaustible energy sources [5]. The amount of energy emitted by the sun is approximately 28000 times that consumed by humans worldwide in one year [6-8]. According to research conducted by the International Energy Agency (IEA), sunlight hitting the earth for 90 minutes can provide enough energy to power the world for one year. According to the countries' energy policies, solar energy is expected to meet 11% of global electrical energy consumption in 2050 [9]. In short-term plans, it is estimated that renewable energy sources will be the energy source with the fastest growth rate with a growth rate of 7.6% until 2030 [10].

Renewable energy financing totalled $226 billion in the first half of 2022, up 11% year on year [11]. The need for clean energy sources to address the ongoing global energy and climate crises is driving the increase in investments. Solar energy investment increased by 33% in the first half of 2021, reaching 120 billion dollars. China became the world's largest investor in solar energy in 2022, with a 173% increase and 41 billion dollars [12-14]. It is making serious investments in renewable energy resources in Europe. Germany aims to meet 80 percent of its electricity needs with renewable energy sources by 2050 [15]. In recent years, Italy has also accelerated the installation of solar power plants, with the installed capacity of solar power plants set to reach 50 GW by 2030 [16].

Türkiye is a country dependent on foreign energy in terms of its known resources. Türkiye can close this dependency with renewable energy sources. Türkiye is a country rich in solar energy. According to the data of the Ministry of Energy, it has been determined that the annual total sunshine duration is 2737 hours (7.5 hours per day), and the annual total incoming solar energy is 1527 kWh/m^2 (a total of 4.2 kWh/m^2 per day) [17-19]. In this case, solar energy in Türkiye due to its high potential, ease of use, renewable and environmentally friendly, it can become widespread rapidly. Although Türkiye is in a very lucky geographical position in terms of solar energy, it cannot use its potential sufficiently. It is possible to use solar energy efficiently in almost every region of the country. The use of solar energy in Türkiye has started to be used for heating the water used in buildings. Today, increasing amounts of solar energy are used to meet the hot water requirement in swimming pools and various facilities, to cool buildings and to generate electricity. The result obtained from all these data is that Türkiye has to supply a significant part of its electrical energy needs from renewable energy sources. This necessity will become vital in the coming years. The Turkish Ministry of Energy aims to supply 30% of its electrical energy needs from renewable energy sources in 2023 [20].

Türkiye has decided to become a party to the Paris climate agreement. This was a very important and appropriate decision to combat climate change. Increasing emissions day by day, how to reach the net-zero emission target on a national scale is a matter of debate. The energy sector has to make maximum efforts to increase power system efficiency to ensure environmental and energy sustainability. Institutions should be directed to renewable energy sources to meet their energy needs. In this context, universities with a large area can transform into green campuses.

In Türkiye, there is a lack of data on the development of sustainable energy green campuses. The aim of this research is to close a gap in the economic and environmental analysis of solar energy. This will inspire universities, where the installation of solar power plants can be profitable, to work on sustainable green campuses to combat climate change.

Solar energy studies have been conducted using software such as PVsyst, PV-Online, System Avisor

Model-SAM, Solar-GIS, and RETScreen [21-23]. In addition, there are PVGIS and PVWatts software programs that have not been researched much in the literature. This study presents a comparison of PVGIS, PVWatts and PVsyst software.

2 MATERIALS AND METHODS
2.1 Geographically Information

Necmettin Erbakan University is located in the province of Konya, which has Türkiye's largest surface area. The university, which has over 35000 students and over 1900 academic staff, has seven different campuses. The Köyceğiz campus is the largest of these campuses. The Köyceğiz campus houses seven faculties. The Köyceğiz campus, also known as the main campus, is still growing. The campus is located at 37°51'53"N and 32°24'53"E latitude and longitude. The height of the campus from the sea is approximately 1011 meters. Due to the advantages of Konya such as high sunshine duration and large campus area, Necmettin Erbakan University is in a suitable location for the installation of solar power plant. The campus area to be analyzed is shown in Fig. 1.

Figure 1 Necmettin Erbakan University Köyceğiz Campus

2.2 Details of Grid Connected Solar PV Power Plant

Large power plants in traditional grid architecture cause the distance between the electricity generation facility and the consumption point to increase. Distributed generation is a method of producing electricity on a small scale at multiple locations near the load. Solar energy will be installed at energy consumption points, reducing power line investments and overall electricity generation costs. The Köyceğiz campus is ideal for the establishment of these facilities. These facilities are environmentally friendly and do not emit carbon dioxide during the production of electrical energy. This situation significantly contributes to the Paris Climate Agreement's reduction of carbon emissions, to which Türkiye is a signatory. Given these circumstances, it is anticipated that 1 MW solar power plant on campus will meet the electrical energy needs of the three central classroom buildings.

With the rapid advancement of technology in the solar field, more and more people began to install solar power systems. Among the various different types of systems installed around the world, the grid-connected solar system is the most preferred. In the grid-connected system, the electricity produced is diverted to the grid from where it is used to power various devices. It is easy to install and maintain. Since there are no moving parts in grid systems, it does not require constant maintenance.

The advantages of the system designed depending on the network are as follows:

- Since storage units such as batteries will not be used in the system, there is no additional cost for storage.
- Since there will be consumption close to the system and there is no storage, the loss will be minimal due to less energy conversion.
- Since the energy produced is connected to the grid, when the produced energy is not enough, the grid will be activated and the energy will feed the load completely.
- While designing the system, it has the flexibility to design according to the desired amount or area, since there is no obligation to cover the entire load.
- If the area is sufficient, the installed capacity of the system can be increased.

The PV system consists of PV cells, but other components are also needed to control, convert and transmit energy such as the PV module, grid connectors, inverters and cables. Grid-connected systems consist of the following basic components.

- Solar panels are preferred as monocrystalline in order to obtain high efficiency.
- Inverters are selected according to the installed power of the plant. Depending on the power of the plant, one or more inverters divided into equal power can be used.
- Grid connection includes transformer, substations and protection systems.
- DC/AC cables are used for mains, panel and inverter connections.

The solar power plant system and its components are detailed in the block diagram shown in Fig. 2.

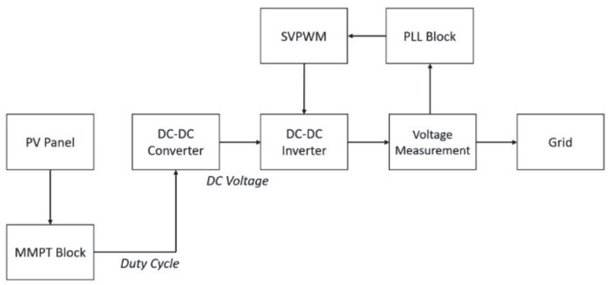

Figure 2 Block diagram of solar PV plant [23]

2.2.1 Meteorological Details and Plant Layout

The province of Konya, located in the south of the country, is quite good in terms of sunshine duration. The monthly incoming radiation value is 1608 kwh/m, which is above the national average. For this reason, Necmettin Erbakan University in Konya was preferred as the study area within the scope of benefit/cost. Therefore, the largest solar power plant of the country is in Konya with an installed power of 1348 MW. The location and energy capacity of Konya in the country are given in Fig. 3.

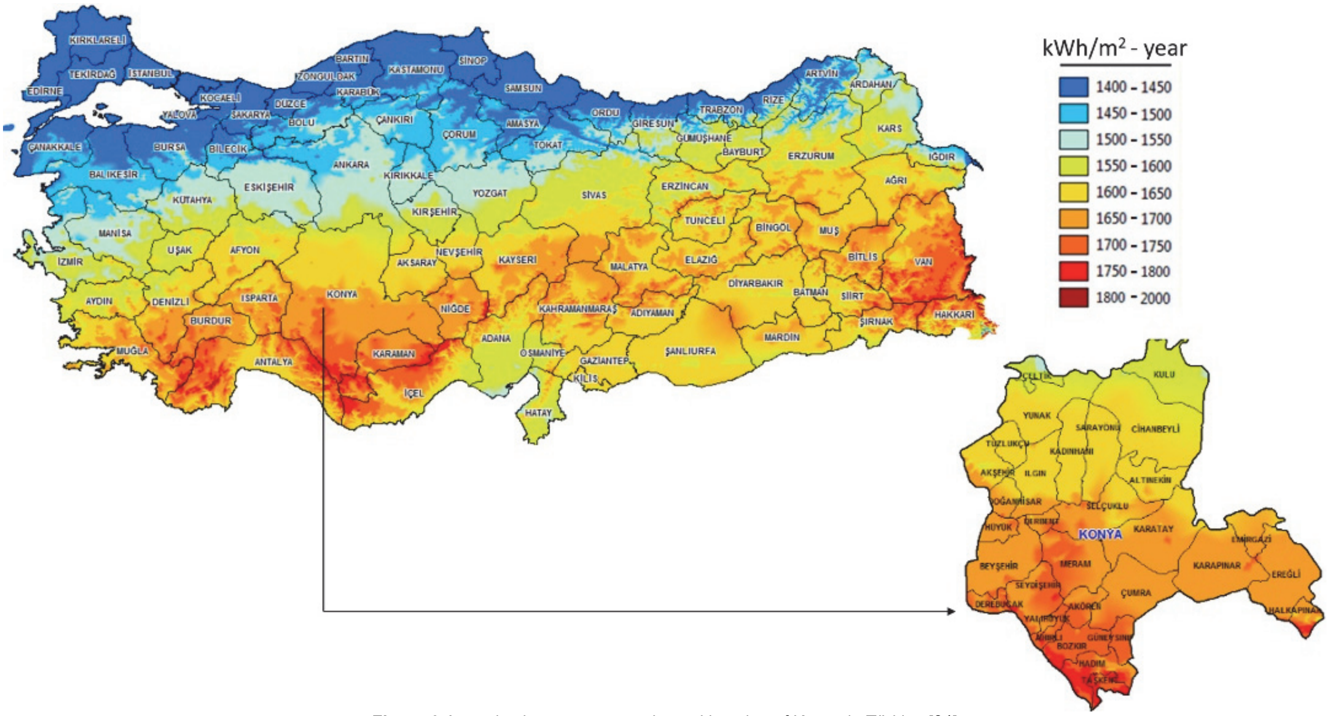

Figure 3 Annual solar energy capacity and location of Konya in Türkiye [24]

The monthly average radiation and temperature values for the region where the study is planned are obtained from the Türkiye Solar Energy Potential Atlas and are given in Tab. 1 [25].

Table 1 Meteorological Details of Konya

Months	Global Radiation / kWh/m^2-day		Sunshine Duration / Hour	
	Türkiye	Konya	Türkiye	Konya
January	1.79	1.98	4.11	4.19
February	2.5	2.56	5.22	5.51
March	3.87	4.23	6.27	6.68
April	4.93	5.2	7.46	8.03
May	6.14	6.3	9.1	9.46
June	6.57	6.78	10.81	11.28
July	6.5	6.81	11.31	11.97
August	5.81	6.05	10.7	11.35
September	4.81	5.12	9.23	9.79
October	3.46	3.73	6.87	7.35
November	2.14	2.35	5.15	5.53
December	1.59	1.77	3.75	3.93
Average	4.18	4.41	7.49	7.92

Table 2 Percentage of Various Losses

Losses	PVGIS	PVWatts	PVsyst
PV module nameplate DC rating	1%	1%	0.97%
Diodes and connections	0.4%	0.3%	0.4%
DC wiring	1.2%	1.2%	1.15%
AC wiring	1%	1%	1%
Shading	0.4%	0.5%	0.65%
Module mismatch	2%	2%	2%
Soiling	1%	2%	2%
Inverter and transformer	6%	6%	6.09%
Aging	1%	1%	1%

The slope is critical for solar power plants to maximize sunlight absorption. It was calculated as 36° in the review in the PVGIS software tool. This PV power plant solar panel is monocrystalline. It has one solar panel rated at 235 W and requires 4260 units. In addition to these methods, the techniques and analyses that can be used are important. Percentage of miscellaneous losses is given in Tab. 2.

2.2.2 Methodology of Performance Analysis

Estimating the amount of energy to be produced by the planned solar power plants is critical. Some issues must be addressed in order for these estimates to be consistent. One of the most important factors to consider when investing in ground-mounted solar power plants is the location of the system. This issue will be critical to the performance of the new power plant. During the planning phase, the solar radiation of the panels and the calculation of the nominal energy of the system should be considered.

The daily solar radiation event in an inclined PV plant with atmospheric conditions is calculated as shown in Eq. (1).

$$H_{\mathrm{at}} = \left[(1-\gamma_T) R_d + \gamma_T \left(\frac{1+\cos\beta}{2} \right) + \rho \left(\frac{1-\cos\beta}{2} \right) \right] \times \times K_{\mathrm{T}} \times H_{\mathrm{o}} \quad (1)$$

where K_{T} represents the aperture index, R_{d} represents the slope factor, T represents the overall slope factor, is the slope angle (in radians), and is the reflection coefficient. H_o denotes the solar radiation event on a horizontal PV module in the absence of atmospheric conditions (kWh/m^2/day), and H_o is calculated using Eq. (2).

$$H_o = \left(\frac{24}{\pi}\right) \times L \times \times \left(\cos\delta\cos\varphi\sin\omega_{sr} + \sin\delta\sin\varphi\cos\omega_{sr}\right) \quad (2)$$

where L represents solar insolation (kW/m^2), δ represents declination angle (in radians), φ represents latitude angle (in radians), and ω_{sr} represents sunrise angle (in radians). The energy produced by the power plant in ideal condition is calculated using Eq. 3.

$$P_a = H_{at} \times \eta \times A \times N \times \left(1 + \beta_T \left(T_{cell} - T_{ref}\right)\right) \quad (3)$$

where A represents the area of each module, N represents the total number of modules, is the efficiency of the PV cell in efficiency, and T represents the power coefficient, which is set to –0.41%/°C. T_{cell} is the temperature of the cell, and T_{ref} is the reference temperature (25 °C). T_{cell} is computed as shown in the Eq. (4).

$$T_{cell} = \left[\frac{\left(\tau\alpha - \eta \times G\right)}{U}\right] + T_{amb} \quad (4)$$

$$U = U_c + \left(U_v \times v\right) \quad (5)$$

$\tau\alpha$ represents the transmittance-absorption product, G is solar radiation (W/m^2) and its standard value (1000 W/m^2) is taken into account. U is the thermal loss coefficient (W/m^{2}K) calculated using Eq. (5). The default value for calculating T_{cell} is constant dissipation factor (U_c) and wind dissipation factor (U_v) 25 W/m^{2}K and 5 W-s/m^{3}K [26].

2.3 Simulation Softwares Used and Procedure

PVGIS is a free online photovoltaic energy calculator simulation program that calculates the solar energy production values of photovoltaic systems and facilities in Europe, Africa, and Asia using solar radiation maps. Google serves as the climate database in the PVGIS simulation program. This application computes a photovoltaic system's monthly and annual solar radiation values by determined parameters such as the desired latitude and longitude parameters on a map, the type and total capacities of the photovoltaic module, the system performance ratio, module mounting features and angles.

PVWatts estimates the power generation and energy costs of grid-connected PV power systems worldwide. It is enough to have basic knowledge about photovoltaic systems. PVWatts makes assumptions about modules, inverter and other parts of the system so there is no need to define detailed information. TMY2 and TMY3 are used as climate databases in the PVWatts simulation program.

The PVsyst program is a simulation program developed by the University of Geneva, Switzerland, that is used to design and analyze photovoltaic systems such as grid-connected or off-grid PV systems, PV irrigation systems, and DC grids [27]. This program, compared to PVGIS and PVWatts programs, allows more detailed calculations and the use of different parameters. The block diagram of the study carried out in 3 different programs is given in Fig. 4.

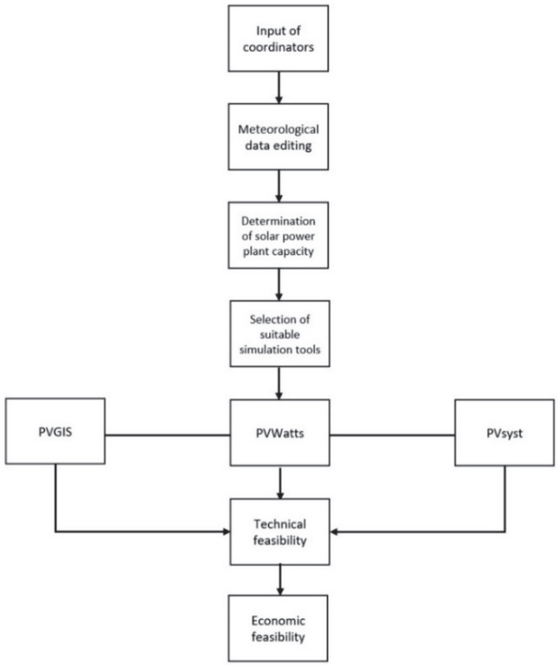

Figure 4 Workflow diagram in blocks

3 RESULT AND DISCUSSIONS

Weather conditions have a direct impact on the efficiency of solar panels and electricity production. Clouds, rain, lightning, hail, or snow effectively reduce the amount of sunlight that can reach solar panel surfaces. Solar panels' energy efficiency will drop dramatically depending on how bad the weather is. With its location, Türkiye is at the north pole, and the Sun path is depicted in Fig. 5 [28].

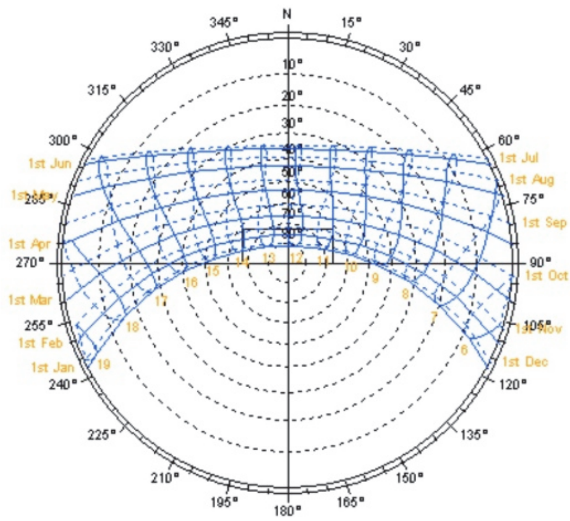

Figure 5 Sun path diagram of working Location

Solar radiation values were calculated using three different software programs: PVGIS, PVWatts, and PVsyst. Solar radiation data by month are given in Fig. 6.

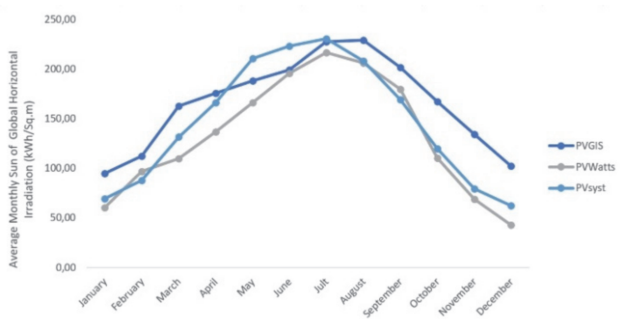

Figure 6 Monthly sun of irradiation for Köyceğiz Campus

Annual energy production amounts made with three different software programs are given in Fig 7. In July, the highest production amount is 224.8 kWh/Sq·m, followed by 214.3 kWh/Sq·m in August. The lowest amount of energy produced is 74.8 kWh in December and 98.8 kWh in January. The results of the various software analyses are similar.

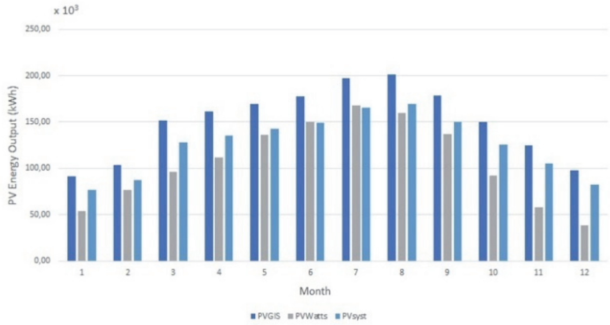

Figure 7 Monthly energy output of 1 MW Solar PV plant

Financial analysis is an important consideration in power plant construction. The cost of energy is critical for feasibility. The plant installation cost and percentages should be calculated clearly in this context. The costs of the components in the power plant installation are given in Fig. 8 as a percentage.

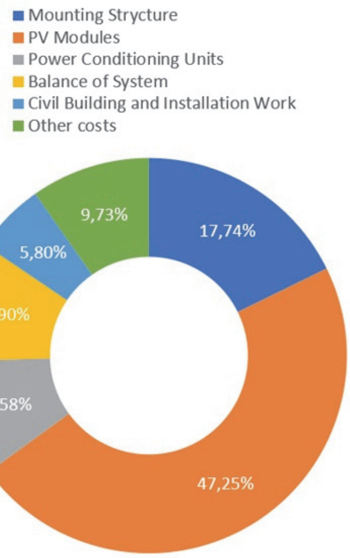

Figure 8 Percentage of solar PV plant component costs

The total investment cost, operating costs, and annual panel yield loss values are all considered when calculating the economic feasibility of the proposed 1 MW solar PV system. The annual operating cost is 1% of the investment cost. It is assumed that the efficiency loss in solar panels decreases by 1% every year. In Tab. 3, an economic feasibility analysis was made using all these costs. Also, Fig. 9 shows the change of positive and negative cash flows over the years. As a result of the analysis, the amortization period of the power plant was calculated as 6.1 years.

Table 3 Economic indicators for 1 MW solar PV system for Köyceğiz Campus

Year	Panel efficiency	Energy production / kWh	Income / ₺	Financial return / ₺
1	1	285415.09	200809.43	–939023.21
2	0.99	282560.94	198801.34	–751507.34
3	0.98	279706.79	196793.25	–565999.57
4	0.97	276852.64	194785.15	–382499.89
5	0.96	273998.49	192777.06	–201008.30
6	0.95	271144.34	190768.96	–21524.81
7	0.94	268290.19	188760.87	155950.58
8	0.93	265436.04	186752.77	331417.89
9	0.92	262581.89	184744.68	504877.09
10	0.91	259727.74	182736.58	676328.21
11	0.90	256873.58	180728.49	845771.23
12	0.89	254019.43	178720.40	1013206.15
13	0.88	251165.28	176712.30	1178632.98
14	0.87	248311.13	174704.21	1342051.72
15	0.86	245456.98	172696.11	1503462.36
16	0.85	242602.83	170688.02	1662864.91
17	0.84	239748.68	168679.92	1820259.36
18	0.83	236894.53	166671.83	1975645.72
19	0.82	234040.38	164663.74	2129023.98
20	0.81	231186.23	162655.64	2280394.15

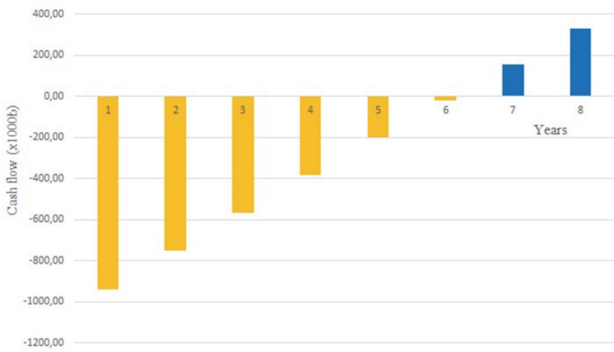

Figure 9 Cumulative cash flow, for PV power plant

The electrical energy production averaged 1685.78 MWh/year based on the results of three different software analyses. Similarly, it is estimated that CO_2 emissions will be reduced by 820.21 tCO_2 per year. These values may be slightly different from the actual values. Weather conditions have a direct impact on the efficiency of solar panels and electricity production. Clouds, rain, lightning, hail, or snow effectively reduce the amount of sunlight that can reach solar panel surfaces. Solar panels' energy efficiency will drop dramatically depending on how bad the weather is. Considering all these situations, the investment to be made seems technically, financially, and environmentally profitable.

4 CONCLUSION

Solar energy has been gaining more and more importance in Türkiye in recent years due to government incentives and public awareness. In this study, a technical and economic analysis of a solar power plant to be built on a university campus was carried out and compared with 3 different programs. This location was chosen due to the high solar energy capacity in this region. The data obtained from the analysis provided information about the amortization period of the plant. According to the data obtained from the study, the system starts to generate profit after the 6th year. In addition, 1 MWp solar power plant can reduce 820.21 tCO_2 greenhouse gas emissions while generating approximately 1685.78 MWh of electricity per year. This study can pioneer the rapid energization of campus areas in different parts of the world with renewable energy sources. In addition, thanks to this study, incentives for renewable energy sources will reduce Türkiye's dependence on foreign sources for electricity generation. In general, this study emphasizes that solar power plants installed in campus environments will contribute to lower energy costs and reduce negative impacts on the environment. In this way, the techno-economic analysis of solar power plants to be installed on campus areas has contributed to the literature.

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