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Research Article

Technoeconomic Evaluation for an Installed Small-Scale Photovoltaic Power Plant

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Solar energy production and economic evaluation are analyzed, in this study, by using daily solar radiation and average temperature data which are measured for 3 years in the Osmaniye province in Turkey. Besides, this study utilizes the photovoltaic- (PV-) based grid connected to a power plant which has an installed capacity of 1 MW investment in electricity production. Economic values show that the net present value (NPV), the first economic method in the research, is about 111941 USD, which is greater than zero. Therefore, the payback year of this investment is approximately 8.3. The second one of these methods, the payback period of the simple payback period (PBP), is 6.27 years. The last method, which is the mean value of the internal rate of return (IRR), is 10.36%. The results of this study show that Osmaniye is a considerable region for the PV investment in electricity production. As a result, investment of a PV system in Osmaniye can be applicable.

1. Introduction

Power production from fossil fuel resources has detrimental effects on the environment considering fossil fuel-induced global climate change and air pollution. The increase in the cost of fossil fuels and soaring consumption of energy resources will both play a critical role in the usage of clean energy in many parts of the world in the near future. In the last decade, the trend of electricity generation from renewable energy has taken the place of conventional fossil fuels throughout the world. Solar energy, one of the main sources of renewable energy, is very convenient for electricity generation. In comparison to fossil fuels, solar energy, as a clean, inexhaustible, and immense energy source, is also one of the most promising renewable energies that present a sustainable alternative electricity generation. Furthermore, the areas where solar energy is used intensively, such as electricity generation, water heating, water pumping in agriculture, lightening, and charging, are application areas in which the use photovoltaic (PV) is easy [1–4]. The usage of PV as a renewable source for reliably producing electricity has grown rapidly for more than 30 years as a result of specific national and transnational incentive programs [5]. Moreover, PV as a usage of utilization of renewable energy sources becomes a popular day-by-day account of high modularity, no requirement for additional resource, not having moving parts, and low-maintenance cost. Another advantage of using PV is that when the growing rate of PV usage increases, the cost of the PV electricity generation decreases steadily [6]. Studies have showed that photovoltaic systems will be broadly used in the future, considering the rapidly decreasing cost of photovoltaic systems. Because price analysis is very important for energy marketing, a review of the cost potential factors on photovoltaic panels was realized, and the expected cost potential of photovoltaic systems was examined considering numerous studies [7].

Researchers have started to carry out economic and technical analyses of a PV power plant to be installed in Turkey. In this context, the producing capacity of grid-connected photovoltaic power plants for 135 locations in Turkey has been investigated [8]. This study has found that although Osmaniye, Dalaman, and Koycegiz have the highest energy generation, Tosya, Gumushane, and Artvin have the lowest energy production. Three separate PV panels for a PV power

Table 1: Solar energy potential for subregions in Turkey [16].

	Average radiation (kWh/m^2/year)	Sunshine duration period				
		Maximum (kWh/m^2/year)	Minimum (kWh/m^2 year)	Average (h/year)	Maximum (h/year)	Minimum (h/year)
Southeastern Anatolia	1492	2250	600	3016	408	127
Mediterranean	1453	2112	588	2924	360	102
General Anatolia	1434	2112	504	2712	381	98
Aegean	1407	2028	492	2726	371	96
East Anatolia	1395	2196	588	2694	374	167
Marmara	1144	1992	396	2528	351	88
Black Sea	1086	1704	408	1966	274	84

plant which has the capacity of 3 kWp for Kahramanmaras are investigated to obtain optimal PV type in terms of thin-film, monocrystalline, and polycrystalline silicon PV panels. The investigation concluded that the system consisting of polycrystals is the most suitable type for the region in terms of the shortest breakeven point for the investment [9]. Solar power generation potential in 2009 for Istanbul was evaluated using the parameters of technical measurements. Moreover, the results obtained using different tariffs, such as time-of-use and feed-in tariffs, show that electricity payments of customers can be decreased by using solar PV systems by more than 40% [10].

Economic analyses of electricity generation from solar renewable energy sources in the world have been investigated by several researches. Hrayshat and Al-Soud [11] show that the total PV installed capacity in Jordan is 82 kWp, generating a total of 182.5 MWh of electricity each year. They use a PV system which has a 5 MWp installed capacity for energy production. Also, economic analysis is calculated using monthly mean values of temperature, global solar radiation, and latitude in RETScreen software.

Furthermore, Al-Badi et al. [12] utilize a 5 MW solar PV power plant for 25 locations in Oman, and the mean energy production value from the PV power plant is found to be 7700 MWh for each year. They conclude that the capacity factor varies between 20% and 14% and the cost of electricity is 250 USD/MWh on average. Another study carries out the economic analysis of a 1.2 MW capacity grid-connected photovoltaic (PV) power plant installed at the Colorado State University-Pueblo [13]. Cash flow economic analysis is performed on a 1 MWp PV power station in Farafenni [14]. Quansah et al. [15] develop analytical models to conduct a technical and economic comparison of grid-charged battery-inverter systems (GBIS) and solar PV with battery storage systems (SPVS). In the study, GBIS is compared with an alternative approach that uses SPVS facility and is designed to meet half (50%) of the user's regular load.

As a result, it is the objective of this paper to verify the economic feasibility of implementing PV solar power in Osmaniye and to examine the economic benefit of solar energy. The rest of the paper will be structured according to the following: Section 1 presents Osmaniye and Turkey's annual solar radiation potential. Section 2 identifies the location of Osmaniye and determines the status of the photovoltaic solar modules. Section 3 examines the economic feasibility of Osmaniye. Section 3 also evaluates the economic viability of solar energy. Finally, Section 4 presents the main conclusions and recommendations.

Table 2: Feed-in tariff and incentives, locally manufactured components, and PV [17].

Locally manufactured component	Bonus (USD cent/kWh)
PV panel integration and production	0.8
PV modules	1.3
PV module cells	3.5
Inverter	0.6
Material which focuses radiation on PV module	0.5
Total	13.3 + 6.7 = 20

2. Materials and Methods

2.1. Solar Energy Potential of Osmaniye. The location of Turkey has a considerable solar energy potential in terms of sunshine duration to produce electricity using PV. The yearly average solar radiation is 3.6 kWh/m^2/day, and the total yearly radiation period is approximately 2640 h, which is sufficient to provide adequate energy for solar applications. The technical and economic usages of solar energy in Turkey are 6105 and 305 billion kWh, respectively. Moreover, the solar energy breakdown in Turkey is shown in Table 1 in terms of subregions. As can be seen from Table 1, the highest average radiation values are in the Southeastern Anatolia and Mediterranean regions, which are 1492 and 1453 kWh/m^2/year, respectively [16].

Renewable energy has been one of the hot topics on Turkey's energy agenda. Significant progress has been made in the field of renewable energy starting from 2005, after the enactment of the Law on Utilization of Renewable Energy Resources for the Purpose of Generating Electrical Energy (Renewable Energy Law (REL)). Investments in renewable energy technologies remained limited between 2005 and 2010 due to the lack of secondary legislation and relatively low feed-in tariff prices. The RE Law of 2010 offers

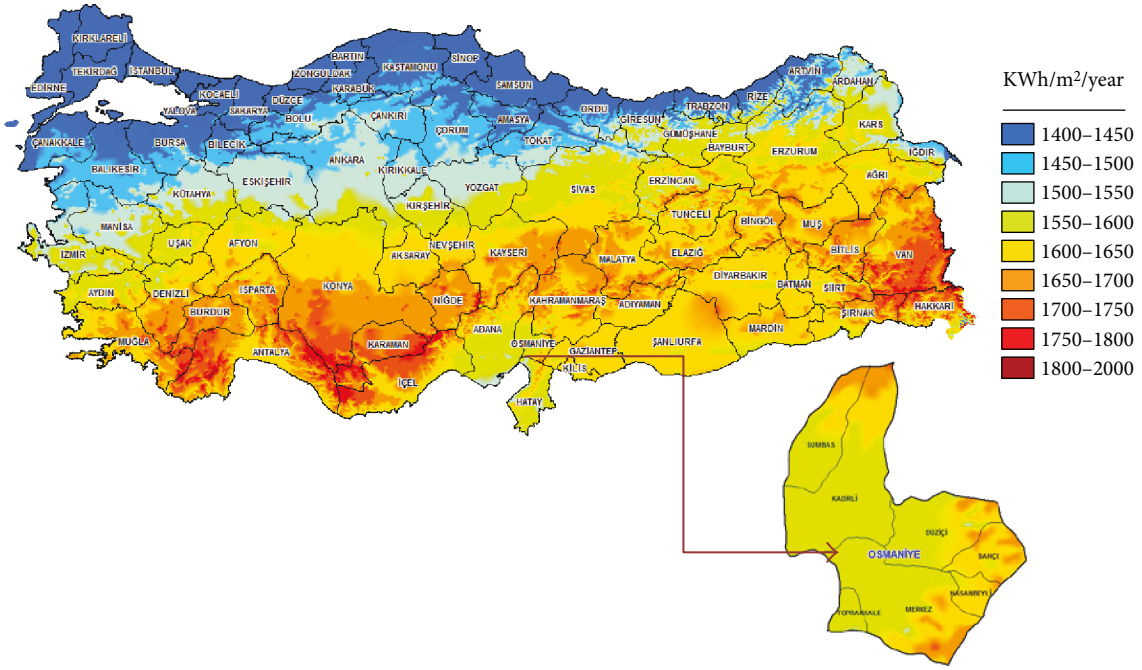

Figure 1: Annual solar energy capacity and location of Osmaniye in Turkey [18].

renewable electricity producers higher FIT rate schemes if they use local components in their projects. Currently, PVs dominate the solar market and global PV installed capacity grew by 74% in 2011. Support and incentives for PV investment in REL is given in Table 2. Generous subsidies around the world have been the main drivers of this significant growth. Even though prices of PVs have fallen dramatically over the years, additional reductions are needed for further implementation [17].

Osmaniye, 37.05 north and 36.14 east, is located in the Mediterranean region in Turkey, as shown in Figure 1 [18]. Solar radiation data in this study were measured every 5 minutes from 22 June 2012 to 01 June 2015 by using a meteorological measuring device (Vantage Pro2 Weather Station) located at the building of the Energy Systems Engineering Department in the campus of Osmaniye Korkut Ata University. A meteorological measuring device was mounted 20 m high from ground level. After the data was measured, the solar energy potential was calculated as averaged values of hourly, daily, monthly, and yearly.

As seen from Figure 2(a), the maximum and minimum total solar radiation occurred in 2013 and 2012, respectively. In addition, the highest monthly average daily radiation of 7.3 kWh/m^2/day was recorded in the month of June, whereas the lowest monthly average solar radiation was 1.6 kWh/m^2/day in December of 2012. It is understood from Figure 1 that monthly averaged values of global solar radiation stay nearly constant every month for each year. As a result, the total value of measured solar radiation based on the year 2013 was about 1.7 MWh/m^2/year for one complete year. Hourly measured monthly average daily global solar radiation during the year 2014 is also shown in Figure 2(b). As can be seen from this figure, the highest and lowest values of monthly averaged total global solar radiation are 695 W/m^2 and 476 W/m^2 in 2014. Considering the monthly values, Figure 2(b) also indicates that the daily mean and maximum solar radiation values are generally higher in summer (May-June-July), whereas comparatively, lower values are seen in winter months (November-December-January).

2.2. Solar PV System Description and Economic Feasibility Analysis. Global radiation, sunshine duration, and temperature as measured data are generally needed to produce electricity with a photovoltaic power plant in a selected region. Therefore, values of average daily measurement data from the meteorological measuring device in Osmaniye are given in Table 3. The table shows that the value of monthly measured average radiation is 136892 kWh/m^2; the value of annual solar duration is 2959 h, and the value of annual average temperature is 18.3°C. Moreover, it is clear that Osmaniye has a significant solar energy potential to produce electricity.

PV modules can be collocated to form a solar array to provide the specific power at a specified voltage and current. In this context, as boundary conditions of this study, a 250 W peak PV module, which encloses polycrystalline silicon solar cells [20], is considered for obtaining 1 MW installed capacity of a power plant which includes 3986 modules calculated using the technical specifications in Table 4. If the PV system is installed on the roof of the building, the roof will be assumed to be a shed roof of 18° tilt made, covering a surface of approximately 6800 m^2 for 1 MW installed capacity.

In the economic viability aspect, the net present value (NPV), payback period (PBP) method, and internal rate of return (IRR) are analyzed in this study. Moreover, net present value (NPV) as an economic indicator is defined as the

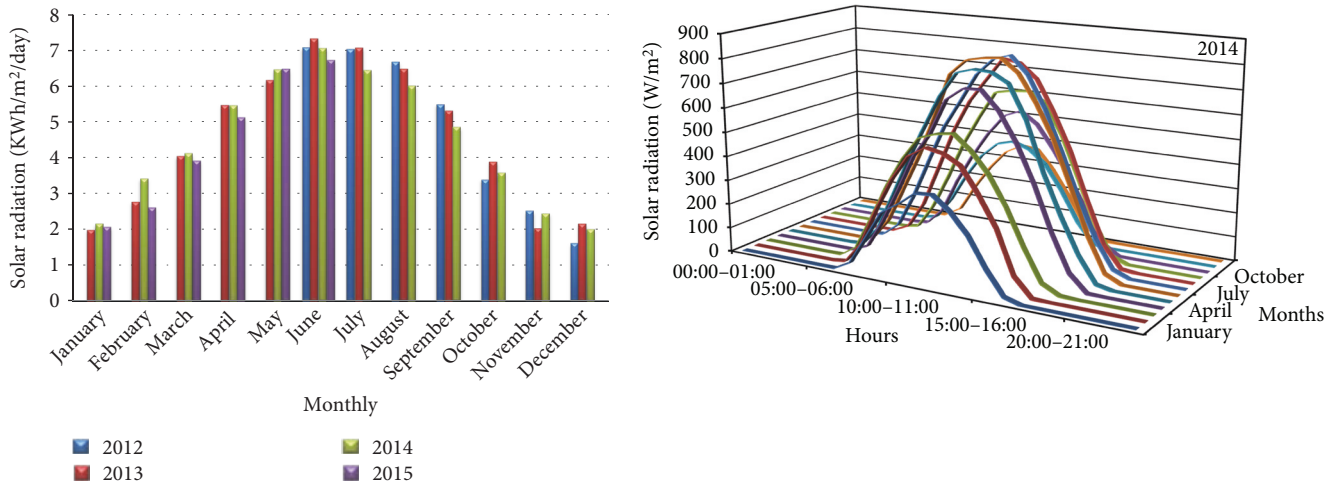

Figure 2: (a) Monthly averages of daily solar radiation throughout 2012–2015. (b) Hourly measured monthly average daily global radiation for 2014.

Table 3: The values of daily average measurement data.

Months	Daily average radiation (kWh/m^2)	Daily average sunshine duration (h) [18]	Daily average temperature (°C) [19]
January	2.09	4.57	8.6
February	3.10	5.66	9.7
March	4.1	6.76	12.7
April	5.48	7.87	16.9
May	6.31	9.83	21.1
June	7.16	11.39	25.2
July	6.85	11.79	27.8
August	6.40	11.19	28.4
September	5.23	10.15	25.3
October	3.64	7.78	20.4
November	2.35	5.92	13.8
December	1.94	4.24	9.7

value of all future cash flows, calculated at the discount rate. Positive NPV represents an indicator of a potentially feasible project [21]. Sowe et al. [14] also provided the following equation:

$$\sum_{n=0}^{N} \frac{B_n}{(1+i)^n} - \sum_{n=0}^{N} \frac{C_n}{(1+i)^n} = \text{PVB} - \text{PVC}, \quad (1)$$

where B_n = expected benefit at the end of the year n, C_n = expected cost at the end of year n, i = discountrate, n = project duration in years, N = project period, PVB = present value benefit, and PVC = present value cost. The payback period (PBP), which is the second economic method applied in this study, is substantially indicated by the payback period of the project as stated in (2). The project investment

Table 4: Technical specifications of a photovoltaic module used [20].

Item description	Item specification	Item description	Item specification
Module number	BYD 250P6-30	Short-circuit current	8.98 A
Efficiency	15.37 percent	Open-circuit current	38 V
Rated power (P_{max})	250 W	Frame area	1.63 m^2
Voltage at P_{max}	30.40 V	Dimension (mm)	1640 × 992 × 50
Current at P_{max}	8.22 A	Weight	19.6 kg

is unacceptable with respect to economics when the PBP presents a high value (long payback periods). PBP does not incorporate the time value of money; moreover, assumptions on discount or interest rates are not required. Otherwise, the shorter PBP indicates the better investment. It is well known that the criterion of PBP value for the availability is higher than the profitability of the PV project. PBP is shown as follows [14, 22]:

$$\text{PBP} = \frac{\text{Initial investment (USD)}}{\text{Annual saving (USD/years)}} = \text{years}. \quad (2)$$

The last applied economic method is the internal rate of return (IRR), calculated by the subtraction of the total present value benefit from the total present value cost. As the IRR is greater than the discount rate, the PV project is considered as satisfactory and worthwhile. The IRR is defined in (3) where i = IRR [14, 23].

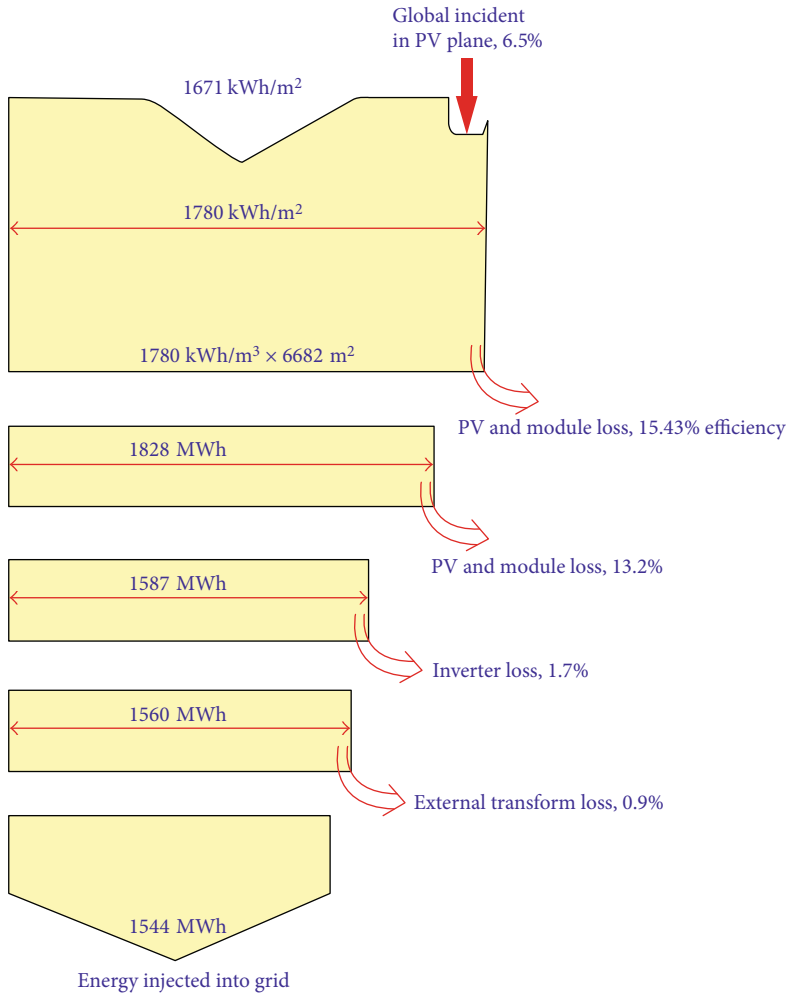

Figure 3: Electricity generation of a proposed solar PV system considering losses [24].

Table 5: Assumption of various interest rates used in the economic feasibility [25].

Item description	Value
Interest rate (TL)	10.79%
Inflation rate (TL)	2.96%
Discount rate (TL)	7.6%
Photovoltaic panel yield loss	8%
Project life	25 years

$$\sum_{n=0}^{N} \frac{B_n}{(1+i)^n} - \sum_{n=0}^{N} \frac{C_n}{(1+i)^n} = 0. \quad (3)$$

3. Results and Discussions

Total investment cost, life cycle of panel sand inverters, fixed operation, maintenance, repairing and utilizing costs, purchasing price offered by the government, and increasing energy costs were considered while calculating the economic viability of a proposed 1 MW solar PV system. Thus, the costs and benefits of solar PV system which will generate electricity into are analyzed and assessed based on the government incentive in Turkey. In this study, it is seen from Figure 2 that measured annual average solar radiation to the horizontal surface is 1671 kWh/m^2. As shown in Figure 3, PV and module loss, inverter loss, and external transform loss are

Table 6: Cost and economic assumption of the PV power plant [1].

Item description	Cost ($)	% of total cost
Feasibility study	9012	0.7%
Development cost	6437	0.5%
Engineering cost	5150	0.4%
Solar PV equipment	1125257	87.4%
Balance of power plant	102998	8%
Miscellaneous	38624	3%
Total initial cost	1287479	100
Annual operation and maintenance	5000	Annual
Depreciation	81000	Annual

Table 7: Economic indicators for 1 MW solar PV system for NPV.

Economic indicators for 1 MW solar PV system for NPV (USD)											
	Years										
	0	1	2	3	4	5	6	7	8	9	10
Income		204961	203692	202473	201308	200201	199156	198179	197275	196449	195709
Expenses		111204	111204	111204	111204	111204	151188	150992	150810	150643	150494
Depreciation expenses		80924	80924	80924	80924	80924	80924	80924	80924	80924	80924
Cash flow		174681	173412	172193	171028	169921	128892	128111	127389	126730	126139
Present value of cash flows	−1287479	162343	149780	138222	127590	117811	83053	76719	70898	65550	60635
Scrap cost (10 years later)	346819										
Present value	1399420										
Net present value	111941										

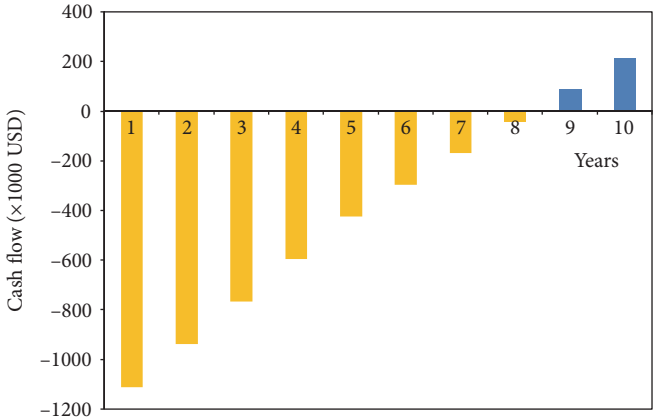

Figure 4: Cumulative cash flow, NPV for PV power plant.

Table 8: Economic indicators for PBP.

Description	Value (USD)
The total annual benefit	68926
Total initial cost	1287479
Scrap value	346819
Depreciation	80924
Repayment period (year)	6.27

Table 9: Economic indicators for IRR.

Discount rate	NPV
$i_1 = 10\%$	+13453
$i_2 = 12\%$	−23277

taken into account while determining total generation electricity of a PV system. Using the study of Verma and Singhal [24], energy injected into grid is calculated as 1544 MWh/year in Osmaniye. The input economical parameters for these three economical methods are summarized in Table 5. The costs of the main parts of the solar PV system are given in Table 6.

PV panels, transportation, and installation are the main equipment for solar PV investment, and its percentage is around 87.4. Balance of plant cost, as the second higher investment cost, accounts for approximately 8% of the total cost. All of these costs and interest rates given in Tables 5 and 6 were used for economic feasibility analysis in this research [1].

NPV is the difference between the present value of investment cash inflow and investment cost. If the NPV is a positive value, the project is potentially feasible. Also, NPV determines whether the project is generally an acceptable investment or not. Table 7 shows that the NPV is greater than zero when the year is approximately 8.3, which is the payback year of this investment. Besides, Figure 4 shows that positive and negative cash flow changes by years.

Table 8 presents the second economic method which is the simple payback method (PBP), and economic indicators for PBP are given in this table. The payback period is 6.27. The quicker the regaining of the cost of an investment is, the more desirable the investment for the basic assumption of PBP is. Consequently, the result of PBP for Osmaniye seems feasible.

The development of a PV project would be acceptable if the IRR is equal to or greater than the required rate of return. Table 9 shows the IRR indicators and the value of the calculated IRR for Osmaniye. As can be seen from this table, the IRR is 10.36%, greater than the discount rate. So, the considered investment appears profitable.

4. Conclusion

Photovoltaic application can provide clean and reliable energy, without noise, and is an environmentally friendly source of power. In addition, the cost of photovoltaic energy technology is gradually decreasing as the market demand and production of PV systems are increasing. This study makes an economic analysis of a solar PV grid-connected system for 1 MW electricity generation plant in Osmaniye and the technical potential of solar PV electricity generation. This research underlined the obtained results given below.

The total value of measured solar radiation was about 1.7 MWh/m^2/year for one complete year. The highest monthly average daily radiation was found to be 7.3 kWh/

m^2/day, whereas the lowest monthly average solar radiation was 1.6 kWh/m^2/day.

The NPV was found to vary between \$100000 and \$120000, while the mean value remained as \$111941. The payback year of this investment in terms of NPV is approximately 8.3, and the PBP varied between 6 and 7 years. PBP was calculated as 6.27 years, and the mean value of the internal rate of return (IRR) was determined as 10.36%. As a result, based on economic indicators and technical results, Osmaniye was found to be the best site for the development of a PV-based power plant.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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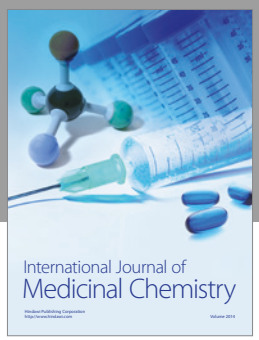

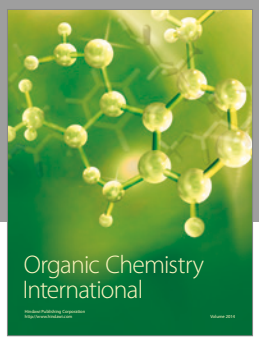

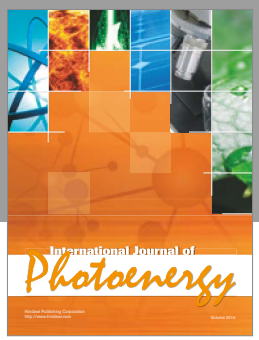

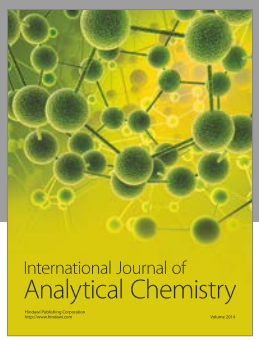

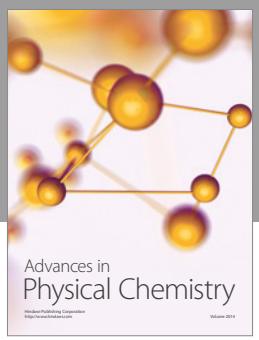

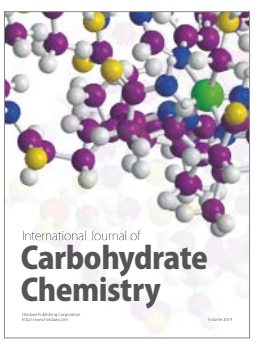

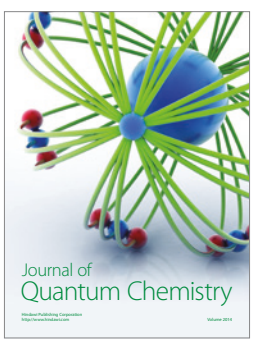

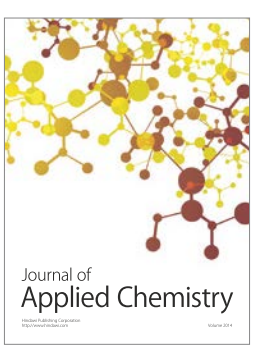

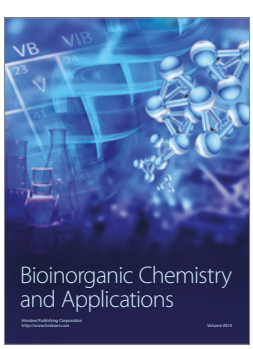

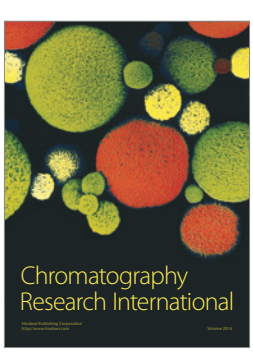

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