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INVESTIGATION OF THE EFFECT OF PV PANEL EFFICIENCY PARAMETER ON INVESTMENT PAYBACK PERIOD

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Abstract

Original scientific paper

The importance of solar energy is increasing due to climate change and similar reasons. However, the biggest barriers to solar energy investments are the high initial investment cost and the long investment payback period. In this study, the effects of technological developments in the investment payback period are examined. It has been investigated how the increase in PV panel efficiency affects the investment payback period of solar energy systems. The annual average profit, the daily gain to be obtained according to the different PV panel efficiency values are calculated, and the effect of different PV panel efficiency values on the investment payback period of 1 MW PV power plant has been investigated. Levelized cost analysis has been used in this study. In the future, it has been found that the payback period of 1 MW PV power plants may be less than 3 years if high-efficiency PV panels take their place in the market.

Keywords: *PV, solar energy, PV efficiency.*

PV PANEL VERİM PARAMETRESİNİN YATIRIM GERİ ÖDEME SÜRESİNE ETKİSİNİN ARAŞTIRILMASI

Özet

Orijinal Bilimsel Makale

İklim değişikliği ve benzeri nedenlerle güneş enerjisinin önemi gün geçtikçe artmaktadır. Bununla birlikte, güneş enerjisi yatırımlarının önündeki en büyük engel, yüksek ilk yatırım maliyeti ve uzun yatırım geri ödeme süresidir. Bu çalışmada, teknolojik gelişmelerin yatırım geri ödeme süresindeki etkileri incelenmiştir. PV panel verimliliğindeki artışın, güneş enerjisi sistemlerinin yatırım geri ödeme süresini nasıl etkilediği araştırılmıştır. Yıllık ortalama kar, farklı PV panel verimlilik değerlerine göre elde edilecek günlük kazanç hesaplanmış ve farklı PV panel verimlilik değerlerinin 1 MW PV santralin yatırım geri ödeme süresine etkisi araştırılmıştır. Bu çalışmada seviyelendirilmiş maliyet analizi kullanılmıştır. Gelecekte, 1 MW PV enerji santrallerinin geri ödeme süresinin, piyasada yüksek verimli PV panellerin yer alması durumunda 3 yıldan az olabileceği ifade edilmiştir.

Anahtar Kelimeler: *PV, güneş enerjisi, PV verim.*

1 Introduction

Economic models have been developed to examine the effects of solar energy on economic growth data. A structural economic model has been developed from those economic models [1]. In the literature, different studies on the economic analysis of solar power plants can be found. In one of those studies, five different power plants with 1, 5, 10, 25 and 151 MW were analyzed by using the leveled electricity cost method [2]. Studies in the literature can be examined in a wide-band range from general topics such as sectoral to specific studies on the feasibility of PV power plants. The review study was carried out emphasizing the importance of site selection for solar power plants. Those studies are an economic feasibility study for investors. In that study, factors that affect the investment have been defined prior to the investment decision considering many parameters which are urban areas, solar radiation and slope [3]. Levelized Cost Analysis is one of the most widely used methods. In that analysis, many input parameters are considered such as the lifetime of the system, share of debt and equity, interest rate on debt, return on equity, weighted average cost of capital (WACC) real which is calculated with an inflation rate, OPEX fix (EUR/kW), OPEX variable (EUR/kWh) [4]. It is also seen in the literature that various analyzes of complex solar energy systems are also made. In one of these studies, detailed research was carried out on the energy and economic efficiency of

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Nomenclature

Abbreviation	
a	empirical constant for climatic conditions
AC	annual capital cost (US$)
b	empirical constant for climatic conditions
d	angle of declination
f	solar constant correction factor
H	sunrise hour angle
h	hour angle
I	Solar radiation (W/m^2)
OM	cost of operating and maintenance (US$)
R_B	solar radiation angle factor
t	duration of solar radiation incoming on the surface of the PV module
$\dot{Z}$	capital cost flow (US$/h)
Greek Letters	
τ	total annual number of hours of the system operates (h)
ψ	exponential change of instantaneous total solar radiation
Sub- and Subscripts	
CI	capital investment
OM	operating and maintenance
GS	solar constant
A	atmosphere
y	horizontal plane
s	solar radiation incoming on the surface of the PV module placed with an optimum angle

desiccant cooling (DEC) systems. For applications, the DEC was configured with both solar air collectors and PV/T [5]. The energy efficiency and economic assessment of solar air-conditioning by absorption chiller applied to the building sector was examined [6]. The biggest obstacle to solar energy investments is factors such as the initial investment cost and financial risks [7]. Due to these financial barriers, the economic evaluation of solar energy systems, feasibility studies and many similar analyzes are carried out by the researchers. In one of those studies, the authors studied the impacts and economic evaluation of the solar PV mirroring system [8]. In solar energy systems, optimal parameters such as optimal energy costs were investigated. Also, reference [9] can be examined for other parameters. Techno-economic analyses, in which optimum parameters for PV investments are determined, are seen to be among the trending topics in the literature [10]. It is known that the two most important analyzes applied before investment for solar power plants are technical and economic feasibility studies [11]. One of these studies, the authors carried out the technical and economic feasibility of a 50 MW solar power plant which is grid-connected [12].

Examining the effect of the increase in panel efficiency on the return on investment in the literature review is a less studied subject. The investment payback period has been calculated according to use PV panels having different efficiency values in a 1 MW PV power plant. Materials and methods used in the study are discussed in the next section.

2 Material and Methods

In this study, a 1 MW PV solar power plant has been analyzed. This solar power plant is assumed that it has different PV efficiency values and the PV power plant was installed in the city of Antalya in Turkey. The city is located in an efficient location in terms of solar energy. In the analysis, the annual sunshine time of the plant will be 98 hours [13]. Monthly sunshine duration varies. For 12 years, the average annual solar radiation is approximately 5 kWh/m2 [13]. The optimum collector angle for Antalya is considered as 33o [24]. The latitude of the considering place is 36o. The efficiency of the PV panels used in emerging countries is about 16%. In this analysis, the properties of the PV panels which will be used in a 1 MW power plant and detailed information on the cost parameters considered within the scope of the study can be found in Ref [14]. Economic parameters to be taken into consideration in this analysis have been expressed for Turkey. The average loans (commercial - US dollar) rate given by banks in Turkey is 5.25% between 2002 and 2020 [15]. This ratio varies according to emerging countries. At the same time, for all other parameters which are not considered in this analysis have been considered as constant. Some of these assumptions are following,

-All year round the weather is sunny.
-Parameters such as humidity, pressure and wind that affect solar radiation have been neglected.
-The decrease in efficiency due to the temperature of the PV panel has neglected.
-The efficiency decrease due to the pollution factor on the surface of the collector is neglected.
-The prices of PV panels with different efficiency values considered in the analysis and the prices of other system components have been considered as constant.

Several studies have been carried out to increase the efficiency of the PV panels. Currently, solar cell efficiency parameters are published by NREL. Considering the data from this source, the highest solar cell efficiency value has been determined as 46% [16]. Considering the determined parameters, the efficiency values of the PV panels used in the plant have been changed. Efficiency values of PV panels are changed from 20% to 45%. The methods and equations considered for the solar radiation values are as follows [14].

$$I_A = \frac{24}{\pi} \cdot I_{GS} \cdot f \cdot \sin d \cdot \sin e \cdot \left(\frac{\pi}{180} \cdot H - \tan H \right) \tag{1}$$

Eq. (2) indicates the value of the daily sunlight [14,17,18].

$$I_y = I_A \cdot \left(a + b \cdot \frac{t}{t_g} \right) \tag{2}$$

$$I = I_y \cdot \left(\frac{\pi}{4 \cdot t_g} \cdot \left(\cos(\frac{180}{2} \cdot \frac{h}{H}) + \frac{2}{\sqrt{\pi}} \cdot (1 - \psi) \right) \right) \tag{3}$$

Eq. (4) shows the value of the solar radiation incoming on the surface of a PV module [14,17,18].

$$I_s = I \cdot R_B \tag{4}$$

Eq. (5) is used for energy production from 1 MW solar power plant

$$P = \eta \cdot I_s \cdot A \tag{5}$$

The methods and equations considered for the economic feasibility are as follows

$\dot{Z}$ is the capital cost flow [19].

$$\dot{Z} = \dot{Z}^{CI} + Z^{OM} \tag{6}$$

Where $\dot{Z}^{CI}$ and $\dot{Z}^{OM}$ indicate the hourly levelized cost of capital investment and operating and maintenance, respectively.

The hourly levelized capital investment cost of the solar power plant ($\dot{Z}^{CI}$) is shown as [14,19]

$$\dot{Z}^{CI} = \frac{AC}{\tau} \tag{7}$$

Hourly levelized operating and maintenance cost ($\dot{Z}^{OM}$) is calculated by using Eq. (8) [14,19].

$$\dot{Z}^{OM} = \frac{OM}{\tau} \tag{8}$$

The cost parameters are presented in Table 1.

In many studies and as previously mentioned, PV power plants are considered as risky investments due to their long payback period.

Table 1. Economical parameters of solar power plants for 1 MW power [14].

Parameters	Costs
PV modules (270 W)	US$ 594,000.00
Inverter	US$ 98,600.00
Other system components	US$ 237,726.00
Other costs	US$ 226,437.00
TOTAL COST	*US$ 1,156,763.34*

The most important parameter affecting the payback period of the system is that the PV panel efficiency is still insufficient. In this study, considering the current economic conditions, the payback period of the system has been determined and compared for different efficiency values of PV panels. The efficiency of PV panels, which are used currently in PV power plant, has been considered as 16.62%. The assuming efficiency values of PV panels are 20%, 25%, 30%, 35%, 40% and 45%. Actually, these efficiency values were determined to investigate the answer to a question. This question is if PV panels having higher efficiency values were used today, what would be the investment payback period of PV solar power plants? In this part of the study, used materials and methods were presented. The data obtained are presented in the results and discussion section

3 Results and Discussion

When the studies and technical reports in the literature are examined, it is seen that there are many parameters that affect the initial investment cost of solar power plants. Considering these parameters that increase the cost, it can be concluded that important topics such as concentrating on R & D and innovation studies, produce the high-efficiency panel, and obtaining cheap raw material should be the priority [20]. The use of high-efficiency PV panels will significantly shorten the payback period of investments in solar power systems. In addition, prolonging of the lifetime of PV panels is an important factor. The lifetime of PV panels is expressed as 25 years in many articles and brochures [14,21]. Improvements in the lifetime of PV panels used in the sector will positively affect the investment in PV power plants. It can be clearly seen that the solar energy sector has serious problems in emerging countries. So how can investment in solar energy be supported globally? The answer to this question is technology. The main parameters that should be examined under the title of technology are PV panel efficiency and the lifetime of PV panels. However, the most attractive parameter for investors is the increase in efficiency of the PV panel. The efficiency of the PV panels is directly related to the payback period of the investment and it can be even more important than other parameters such as price and lifetime of the PV panel. Technological developments guide the future of the solar energy sector. Technologically, PV efficiency is increasing day by day. Many useful findings such as payback period of the investment, profit and loss situation can be obtained according to economic conditions of today and different PV panel efficiencies. When the PV panels assumed to have different efficiency values are used in a 1 MW PV power plant, the daily gain amounts in the plant can be calculated. These findings are shown in Fig. 1.

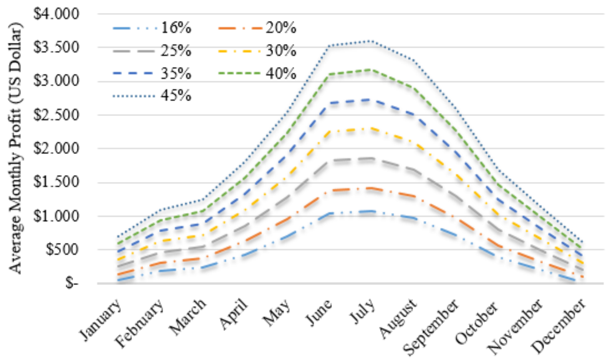

Figure 1. Average daily profit of 1 MW PV power plant according to different PV efficiency values

When the data in Fig. 1 are examined, it is seen that net profit is around 3500 dollars per day with using of the PV panels which have 45% efficiency in summer. When the efficiency value (16%) of the PV panels, which currently use in the solar market, is considered, it is seen that PV power plant makes a net profit of around US$ 1000 per day in the summer months. When these two efficiency values are compared, it is seen that the profit from the plant using PV panels having the efficiency of 45% is 3.5 times higher than that from 1 MW PV power plant using existing PV panels (16%). Average yearly profit from 1 MW PV power plant according to different efficiency values of PV panels in the scope of the study is given in Fig. 2.

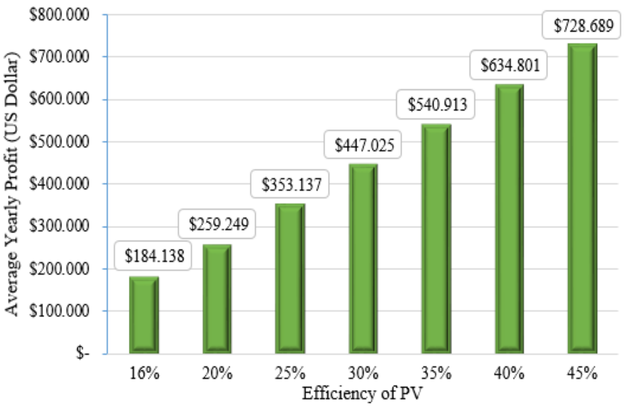

Figure 2. Average yearly profit of 1 MW PV power plant according to different PV efficiency values

When the data in Fig. 2 is examined, annual net profit status is expressed according to different efficiency values of the PV panels. It can be assumed that the investment payback period of 1 MW PV power plant should be less than 3 years. It is seen that the choice of PV panels having efficiencies of 30% or more will provide a very attractive advantage for the investor. High-efficiency PV panels will change their perspective on PV power plants, which are considered a risky investment by financial institutions. These results show that financial barriers, one of the biggest barriers to PV power plants, can be overcome via technological advances. In this analysis, it should be noted that PV panel prices have been assumed to be constant for each efficiency values. The increase in PV panel efficiency will also have an upward impact on panel prices. Also, changes in the capacities of the system components need to be taken into account. It will be very difficult to estimate the price for the future. The findings show the importance of R & D for solar energy. The investment payback periods of the 1 MW PV power plant according to the different efficiency values considered within the scope of the economic analysis are given in Table 2.

Table 2. Payback period of the 1 MW PV power plant according to different efficiency values of PV panels

PV panel efficiency values	Payback period of the investment cost
16%	6 year – 3 month
20%	4 year – 5 month
25%	3 year – 3 month
30%	2 year – 7 month
35%	2 year – 2 month
40%	1 year – 9 month
45%	1 year – 7 month

The most important objective of investors in emerging countries is to maintain the value of deposits of them against high inflation. The economic feasibility shows that there will be a significant increase in the investments to be made in PV power plants by obtaining high-efficiency PV panels with advanced technological solutions and studies. Therefore, technological developments in solar energy should be given more importance. In particular, the necessity to increase the funds allocated for investments in solar cells has been clearly stated by the findings of this study. It can be concluded that PV panels with high efficiency will create very attractive opportunities for investors. PV panel efficiency used in developed countries is about 20% values. In emerging countries, PV panels having a lower efficiency of 16 - 17% are used. It is seen that the efficiency value of the PV panels used in solar power plants has a significant effect on the payback period of the investment costs. The use of solar energy is increasing despite many barriers. In the long term, solar energy is predicted to have a 10% share in global energy production by 2050 [22].

4 Conclusion

The high initial investment costs and the long investment payback period of solar power plants are directly related to PV panel efficiency. When the solar market will launch high-efficiency PV panels, the solar energy sector will be stronger against global economic shocks and global risks. The PV panels having high efficiency will be used in the PV power plants in the future and the investment payback period will decrease. The data show that high-efficiency PV panels will more profit than the current PV panels in the future. The use of panels with PV efficiencies of 30% or more provides payback period which is less than 3 years. It may a long time for the PV panels with high efficiency to take their place in the market. Investment and production costs, easy production and the need for advanced technology should be considered to produce high-efficiency PV panels.

Declaration

The authors declare that the ethics committee approval is not required for this study.

References

[1] Farhidi, F. (2017). Solar impacts on the sustainability of economic growth. Renewable and Sustainable Energy Reviews, 77, 440-450.Farhidi, F. (2017). Solar impacts on the sustainability of economic growth. *Renewable and Sustainable Energy Reviews*, 77, 440-450.

[2] Bano, T., & Rao, K. V. S. (2016). Levelized electricity cost of five solar photovoltaic plants of different capacities. *Procedia Technology*, 24, 505-512.

[3] Rediske, G., Siluk, J. C. M., Gastaldo, N. G., Rigo, P. D., & Rosa, C. B. (2019). Determinant factors in site selection for photovoltaic projects: A systematic review. *International Journal of Energy Research*, 43(5), 1689-1701.

[4] Kost, C., Shammugam, S., Jülch, V., Nguyen, H.-T., & Schlegl, T. (2018). *Levelized Cost Of Electricity Renewable Energy Technologies*. Retrieved August 2, 2021, from https://www.ise.fraunhofer.de/content/dam/ise/en/documents/publications/studies/EN2018_Fraunhofer-ISE_LCOE_Renewable_Energy_Technologies.pdf

[5] Beccali, M., Finocchiaro, P., & Nocke, B. (2009). Energy and economic assessment of desiccant cooling systems coupled with single glazed air and hybrid PV/thermal solar collectors for applications in hot and humid climate. *Solar energy*, 83(10), 1828-1846.

[6] Bouhal, T., Aqachmar, Z., Kousksou, T., El Rhafiki, T., Jamil, A., & Zeraouli, Y. (2020). Energy and economic assessment of a solar air-conditioning process for thermal comfort requirements. *Solar Energy*, 208, 101-114.

[7] Sirin, S. M., & Sevindik, I. (2021). An analysis of Turkey's solar PV auction scheme: What can Turkey learn from Brazil and South Africa?. *Energy Policy*, 148, 111933.

[8] Simon, S. P., Kumar, K. A., Sundareswaran, K., Nayak, P. S. R., & Padhy, N. P. (2020). Impact and economic assessment on solar PV mirroring system–A feasibility report. *Energy Conversion and Management*, 203, 112222.

[9] Numbi, B. P., & Malinga, S. J. (2017). Optimal energy cost and economic analysis of a residential grid-interactive solar PV system-case of eThekwini municipality in South Africa. *Applied Energy*, 186, 28-45.

[10] Zhao, Y., Yu, B., Yu, G., & Li, W. (2014). Study on the water-heat coupled phenomena in thawing frozen soil around a buried oil pipeline. *Applied thermal engineering*, 73(2), 1477-1488.

[11] Khajepour, S., & Ameri, M. (2020). Techno-economic analysis of a hybrid solar Thermal-PV power plant. Sustainable Energy *Technologies and Assessments*, 42, 100857.

[12] Obeng, M., Gyamfi, S., Derkyi, N. S., Kabo-bah, A. T., & Peprah, F. (2020). Technical and economic feasibility of a 50 MW grid-connected solar PV at UENR Nsoatre Campus. *Journal of Cleaner Production*, 247, 119159.

[13] Turkish State Meteorological Service. *Turkey Average Global Solar Radiation Many Years (2004-2016) Heliosat Model Products (Antalya)*. Retrieved March 13, 2019, from https://www.mgm.gov.tr/veridegerlendirme/il-ve-ilceler-istatistik.aspx?m=ANTALYA.

[14] Gürtürk, M. (2019). Economic feasibility of solar power plants based on PV module with levelized cost analysis. *Energy*, 171,

[15] Turkey Cbotro. *Commercial (Opened in USD) (Flow Data,%)*. Retrieved October 28, 2020, from https://evds2.tcmb.gov.tr/index.php?/evds/serieMarket/collapse_3/5010/DataGroup/english/bie_mt210ags/.

[16] National Renewable Energy Laboratory (NREL). *Best Research-Cell Efficiency Chart*. Retrieved March 13, 2019, from https://www.nrel.gov/pv/cell-efficiency.html. 866-878.

[17] Duffie, J. A., & Beckman, W. A. (1991). Solar Engineering of Thermal Processes John Wiley & Sons. Inc. *New York*.

[18] Kılıç, A., & Öztürk, A. (1983). Günes Enerjisi. *Kipas Dağıtım ve Yayıncılık* (book in Turkish).

[19] Bejan, A., Tsatsaronis, G., & Moran, M. (1996). Thermal Design and Optimization John Wiley and Sons. Inc. *New York*.

[20] Dincer, F. (2011). The analysis on photovoltaic electricity generation status, potential and policies of the leading countries in solar energy. *Renewable and sustainable energy reviews*, 15(1), 713-720.

[21] Byrne, J., Taminiau, J., Kim, K. N., Lee, J., & Seo, J. (2017). Multivariate analysis of solar city economics: Impact of energy prices, policy, finance, and cost on urban photovoltaic power plant implementation. *Wiley Interdisciplinary Reviews: Energy and Environment*, 6(4), e241.

[22] Timilsina, G. R., Kurdgelashvili, L., & Narbel, P. A. (2012). Solar energy: Markets, economics and policies. *Renewable and sustainable energy reviews,* 16(1), 449-465.