Profitability Evaluation of Photovoltaic Power Plant Using Software Tools

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Abstract. *A comprehensive analysis of technology or project investment involves evaluating each year of the investment's duration, accounting for direct, indirect, and general costs, taxes, investment contributions, and environmental impacts. In economic analyses of PV systems, key factors include initial system costs and annual energy output, with the system's viability depending on the cost of the replaced energy and repayment methods. The PV power plant (44.41°N, 18.66°E) has four strings, oriented south at a 30° slope. Profitability was analyzed using PVSyst and SAM software, allowing for a comparison of options. Key results include net present value, payback period, and return on investment ratio. Simulated production data provides insights into annual and accumulated balances over the system's expected lifetime, comparing costs with income based on electricity pricing. This approach offers a clear understanding of the project's financial development throughout its lifespan.*

1 Introduction

The purpose of economic analysis is to assess the profitability of an investment, forming the basis for investment decisions. Photovoltaic (PV) systems necessitate a thorough economic evaluation, factoring in initial expenses, annual energy output, and economic incentives like tax credits. When designing grid-connected PV systems, it is essential to consider both tracking and fixed system costs, as well as installation costs measured in dollars per watt ($/W). Financing typically involves loans with interest, alongside an analysis of tax credits that help lower annual expenses, thereby enhancing the market competitiveness of the electricity generated. A comprehensive analysis enables investors to evaluate the economic viability of the PV system, considering all pertinent factors. Unlike on-grid photovoltaic (PV) systems, where the price of electricity produced is compared to the market price, in stand-alone PV systems the price of electricity is compared to the fuel costs of the backup generator that would be used when the PV system cannot produce power. To determine the costs of stand-alone systems, it is necessary to size the system, whereby the storage capacity and losses are determined, based on an estimate of the typical load to be supplied in a certain period. For system sizing, it is necessary to know the energy consumed by consumers during the working cycle, which includes actual measurements of the active and idle state of the device [1].

2 Elements of economic analysis of grid PV systems

The most important factors in the economic analysis of photovoltaic systems are the initial costs and the annual delivered energy. The sustainability of the system depends on the price of delivered energy, tax benefits, economic incentives, and the way the system is paid off. The key analyses during design are the choice of the type of system (fixed or with tracking) and the analysis of the justification of the investment. A detailed economic analysis includes an estimate of operation and maintenance costs, utility electricity costs, loan terms, income tax, system life, and system removal cost. Installation costs are expressed in $/W per peak power, taking into account DC or AC power and trackers. Systems with tracking often have additional costs but can be more cost-effective. Financing often includes loans, and the annual loan repayment depends on the interest rate and repayment period. Tax credits reduce costs through the recognition of interest as tax-allowable expenses. The price of electricity is calculated as the investment cost divided by the annual energy production and is used as a measure of savings compared to the market price. State subsidies further reduce costs and make the produced electricity more competitive on the market [2].

3 Economic evaluation of PV power plant

In this chapter, an overview of the economic and financial analysis of a photovoltaic power plant using two software tools, System Advisor Model - SAM and Photovoltaic System Study - PVSyst, is given, with a comparison of the obtained results. The photovoltaic power plant is located at the location 44.41° 18.66ˈ. The power plant is with fixed support, without the influence of the shadow, oriented towards the south with an azimuth of 180°, and the entire construction inclines 30°. It consists of 4 arrays with 21 Seraphim SRP-250-6PB modules each. An inverter type REFUsol 20K SCI was used.

2.1 Photovoltaic power plant evaluation using System Advisor Model-SAM

The System Advisor Model was created to help potential users or investors determine whether the planned project meets their construction needs in terms of technical and economic profit. SAM offers the possibility of modeling different financial models that calculate the cash flows of the project during a certain period of analysis. The cash flow includes the value of the electricity produced by the system, incentives, installation, operation and maintenance costs, taxes and debts [3] [4].

According to the type of financial model, the considered photovoltaic power plant is a commercial project that sells all the produced electricity at a retail price. Residential and commercial projects are financed through a loan or cash payment. These projects recover investment costs by selling electricity at prices set by the electricity service provider. SAM calculates metrics for these projects, assuming a single investor develops, owns, and manages the project. SAM calculates the Levelized Cost of Energy (LCOE), net present value (NPV) of the after-tax cash flow and the payback period. The payback period is the year when the cumulative sum of the annual savings is greater than the cumulative sum of annual payback cash flows. For commercial projects:

$$\begin{aligned}&\text{Savings in Year}\\&n>0=\\&\text{Value of Electricity Savings in Year } n>0\\&\times(1-\text{Effective Tax Rate})\end{aligned} \quad (1)$$

The cash flow (CF) in Year zero is the net capital cost, equal to the total installed cost reduced by any investment-based incentive (IBI) and capacity-based incentive (CBI) amounts. The installed cost is a positive number, but in the cash flow the signs are reversed so that a negative number for the cash flow in Year 0 indicates a net outflow of cash. For commercial projects:

$$\begin{aligned}&\text{CF for payback in Year } n>0=\\&\text{Value of electricity savings }\times(1-\text{Effective Tax Rate})\\&+\text{State Tax Savings}+\text{Federal Tax Savings}+\\&\text{Total PBI}(\text{Production based incentives})\\&-\text{Debt Interest Payment}\times\text{Effective Tax Rate}\\&-\text{Total Operating Expenses}\end{aligned} \quad (2)$$

Commercial projects additionally include depreciation, determined by the rate and period of depreciation [1]. Installation and operating costs represent the most important part of the input parameters of the economic analysis of the PV system. Installation costs are the initial costs of investing in the system and they consist of direct and indirect costs of the system. The distribution costs of the photovoltaic power plant is shown in the Table 1. The principal amount of the loan or the borrowed amount is automatically calculated as:

$$\begin{aligned}&\text{Principal Amount }(\$)=\\&\text{Total Installed Cost }(\$)\times\text{Debt Fraction }(\%)\end{aligned} \quad (3)$$

Based on the share of debt in investments, the average weighted cost of capital is determined according to the formula:

$$WACC=\left[\begin{array}{l}\frac{\text{Nominal Discount Rate}}{100}\cdot\left(1-\frac{\text{Debt Percent}}{100}\right)+\\\frac{\text{Debt Percent}}{100}\cdot\frac{\text{Loan rate}}{100}\cdot\left(1-\frac{\text{Effective Tax Rate}}{100}\right)\end{array}\right]\cdot 100 \quad (4)$$

Table 1 Distribution of costs for the installation of a photovoltaic power plant

PV modules	52%
Inverter	8%
Balance of system equipment	8%
Construction	8%
Installation labor	4%
Expense of replacing the inverter	1%
Contingency cost	1%
Permitting-Environmental	9%
Grid Interconnection	7%
Land preparation, construction works	2%

The nominal discount rate is based on the values of the real discount rate and the inflation rate:

$$\text{Nominal Discount Rate}=\left[\begin{array}{l}\left(\frac{1+\text{Real Discount Rate}}{100}\right)\times\\\left(\frac{1+\text{Inflation Rate}}{100}\right)-1\end{array}\right]\times 100 \quad (5)$$

The effective tax rate is a single number that includes both the federal income tax rate and state income tax rate:

$$\text{Effective Tax Rate}=\left[\begin{array}{l}\frac{\text{Federal Tax Rate}}{100}\times\left(\frac{1-\text{State Tax Rate}}{100}\right)+\\\frac{\text{State Tax Rate}}{100}\end{array}\right]\cdot 100 \quad (6)$$

Financial parameters important for the evaluation of the photovoltaic power plant using the SAM program are:

Debt fraction =90%; Loan term=3 years; Loan rate 7%/year; Analyssis period=25 year; Inflation rate=2.5% ; Real discount rate=10%; Nominal discount rate=12.75%; Federal income tax rate=10%.

Based on the entered parameters, simulation results of the performance and the financial model are shown in the Table 2. The economic evalution of the PV power plant also depends on the production of electricity. Electricity production depends on the amount of solar radiation on the system and on the capacity of the system. The National Solar Radiation Database (NSRDB) is used to determine the amount of solar radiation at the geographical location of the PV power plant. It is a complete collection of hourly and half-hourly meteorological data on solar radiation.

Based on the analysis, the photovoltaic power plant would produce 26.280 MWh in the first year of the investment. Annual delivered electricity to the grid during 25 year period is shown on the (Figure 1). It is possible to read the production of electricity in any day or hour.

Table 2 Simulation results of PV system perfomed in SAM

Metric of Performance	Value
Annual energy in year 1	26.280 MWh
DC capacity factor in year 1	14.3 %
Energy yield in year1	1253 kWh/kW
Performance ratio in year 1	0.85
LCOE levelized cost of energy nominal	14.30 ¢/kWh
LCOE levelized cost of energy real	11.83 ¢/kWh
Electricity bill with system (year 1)	-8928 $
Net savings with system (year1)	8928 $
Net present value	32019 $
Simple payback period	3.6 god.
Discounted payback period	5.2 god.
Net capital cost	29086 $
Equity	2909 $
Debt	26178 $

The Annual AC Energy value in the Metrics table is electricity delivered by the system in Year 1 of its operation. Its value depends on the type of modeling project. Annual AC Energy in year 1 is the total net electricity delivered to the grid and load (Figure 2). This is the electricity used to reduce the project owner's annual electricity bill. In that case all produced energy is delivered to the grid.

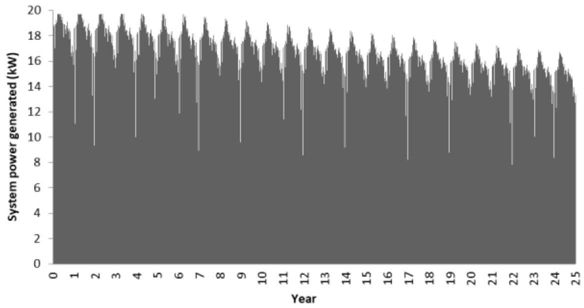

Figure 1 System power generated during lifetime of PV plant

The capacity factor is the ratio of the electrical output power of the system in the first year of operation and the electrical output power of the system that would operate at nominal capacity according to the values on the plate, for every hour of the year. The performance ratio is a measure of the photovoltaic system's annual electricity production in kWh_{AC} and its nameplate capacity in kWh_{DC}, taking into account solar radiation at the system location, and shading and soiling of the array.

3.1 Economic evaluation of PV power plant using PVSyst

PVsyst is a software used in the field of renewable energy sources for optimal design of solar power plants and evaluation of the energy obtained [6].

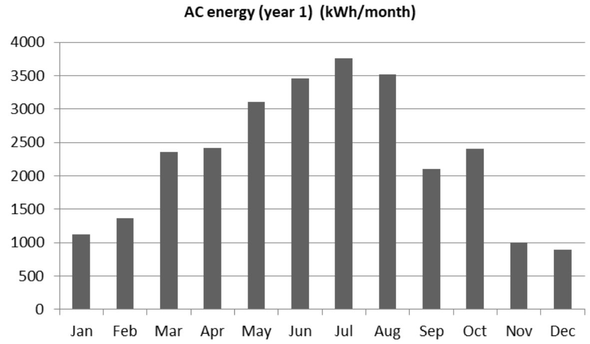

Figure 2 Electricity net generated to the grid in the first year of considered period

PVsyst simulates system performance under different conditions using hourly, daily or monthly data, taking into account solar radiation, temperature and shading. It enables the selection of the exact geographical location of the power plant and pulls meteorological data to estimate the annual solar irradiation. Its integrated Meteonorm meteorological data base and model base of various modules and inverters provide advantages over SAM, as they speed up the analysis process and eliminate the need for manual modeling of components [5]. The most important results of the financial analysis are the net present value, the payback period and the investment return ratio, whose values are shown in the Table 3.

Table 3 Simulation results of PV system perfomed in PVSyst

Annual AC energy in year 1	25.5 MWh/year
Performance ratio in year 1	0.86
Total annual costs	1645 $/god
LCOE	0.1272 $/kWh
Net Present Value	33357 $
Payback period	4.9 god.
Return on investment (ROI)	114.7 %

The return on investment ratio represents the ratio of the net benefit at the end of system life compared to the total investment and measures the profitability of the system. For the system to be profitable, the return on investment ratio must be positive. The analysis at PVsyst showed that the payback period is 4.9 years. In (Figure 3) the cash flow in all years of the investment is shown.

3.2 Comparison of analysis results using SAM and PVSyst programs and actual generation

The simulation results in both programs mostly depend on the produced electricity. SAM and PVsyst showed different results of produced electricity in the first year of the investment. The simulated produced electricity is the result of input data on the amount of solar radiation on the system as well as the performance and losses of the system.

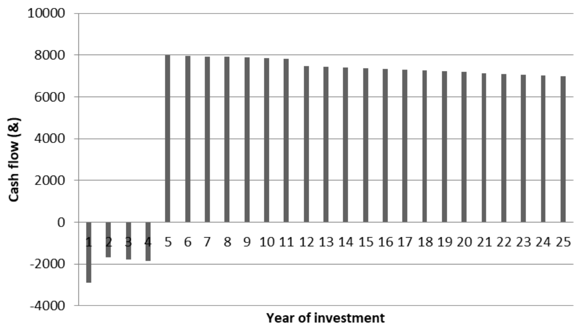

Figure 3 The annual net profit

Given that the performance ratio in both software packages is the same, it can be concluded that the losses of the system model in both programs are the same, and they did not affect the different production results. Therefore, the differences arose due to the use of different meteorological databases. SAM uses the Typical Meteorological Year (TMY) meteorological database published by NREL and is based on an analysis of the National Solar Radiation Database (NSRDB), downloaded from the NSRDB site [7]. PVsyst uses the Meteonorm integrated meteorological data library [6]. In order to determine which program gives more accurate results, it is necessary to establish the percentage difference in relation to the actual production of the system.

$$difference(\%) = \frac{Actual\ generation - Simulated\ generation}{actual\ generation} \cdot 100\%$$

In Table 4 the production data is obtained by simulation in SAM and PVsyst. The actual production of the power plant is 26.15 MWh/year.

Table 4 Generation of PVsystem using SAM and PVSyst

	SAM	PVsyst
Annual AC energy in year 1	26.28 MWh/year	25.5 MWh/year
Performance ratio in year 1	0.85	0.85
LCOE	0.1183 $/kWh $/kWh	0.1272 $/kWh
Net Present Value	32019 $	33357 $
Payback period	3.6 year	4.9 year

SAM software package provides results that are closer to the actual production of the PV system. It is shown that there are discrepancies in the financial analysis in terms of earnings in the first year, LCOE and NPV, which further affect the payback period. All parameters depend on the costs of the system, the selling price of electricity and the amount of electricity produced. Because they were entered manually into the program, the input variables of the financial analysis are the same in both packages. It can be concluded that the different financial results are also a consequence of electricity production. Small differences in the amount of produced electricity resulted in large deviations in the final profitability of the project, as shown by the net present value from Table 4. Both packages showed that the PV power plant is a profitable investment with a payback period that is acceptable to the investor.

4 Conclusion

A simpler way to assess the profitability of a photovoltaic system is through various software programs. They use a range of significant data, such as balances, meteorological data, incident energy, system losses, and inverter and module characteristics. Based on the given input parameters (direct and indirect costs, subsidies, price of electricity), these programs provide insight into the profitability of the system and the investment return period. The PV power plant is simulated in the PVSyst and SAM software packages. Both programs use meteorological data about the location to estimate the annual radiation, which is crucial for the production of electricity. PVSyst has the advantage of an integrated base of meteorological data. The most important results are net present value, payback period, investment return ratio, and annual balance sheet costs. The analysis shows that both programs give nearly the same results, but PVSyst is easier to use, with a richer database of components. SAM gives more accurate results, but does not have a built-in meteorological database and requires data entry in dollars, adapted to the US market. PV power plant is a profitable investment with a payback period of a maximum of 5 years, or up to 7 to 8 years with an expected reduction in electricity purchase prices. The service life of the power plant is 25 years, with the possibility of longer operation of the components.

5 References

[1] K.H.Ibrahim, A.Y.Hassan, A.S.Abd Elrazek,S.M.Saleh, Economic analysis of stand-alone PV-battery system based on new power assessment configuration in Siwa Oasis – Egypt, Elsevier, 2022

[2] D. J. P. T. H. W Short, A Manual for the Economic Evaluation of Energy Efficiency and Renewable Energy Technologies, NREL, Mart 1995

[3] System Advisor Model, https://sam.nrel.gov/financial-models/residential-and-commercial

[4] Y. Aziz, A.K.Janjua, M. Hassan, M. Anwar, S. Kanwal, M. Yousif, Techno-economic analysis of PV systems installed by using innovative strategies for smart sustainable agriculture farms, Springer,Volume 26, pages 5003–5024, (2024)

[5] A. Mermoud,B. Wittmer, PV Syst User Manual, 2014.

[6] D. Dey, B.Subudhi, Design, simulation and economic evaluation of 90kWgrid connected Photovoltaic system, Elsevier Research paper, Energy Reports 6 (2020) 1778–1787

[7] Photovoltaic Geographical Information System, https://re.jrc.ec.europa.eu/pvg_tools/en/#MR