Journal of Electrical Engineering, Electronics, Control and Computer Science – JEEECCS, Volume 9, Issue 31, pages 23-32, 2023

Analysis of Solar System Models Using System Advisor Model Simulations

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***Abstract*–Due to rapid consumption of conventional energy resources which include fossil fuels like coal, oil and natural gas and the need for clean green energy, the significance of renewable energy has increased. Moreover, the hazards of global warming and acidic rain have forced scientists and environmentalists to pursue alternative sources of energy. Solar and wind are the two most vital kinds of renewable energy sources. However, this paper will focus on analysis of solar energy. Photovoltaic cells, or more commonly known as solar cells, play an important role in converting solar energy into usable electrical energy. This paper analyses three different models of solar cells for two different locations with respect to various parameters such as annual energy, capacity factor, energy yield, performance ratio, Levelized Cost of Electricity and Levelized Power Purchase Agreement price. Two distinct arbitrary locations in USA have been chosen to carry out the desired analysis. These locations include Sky Harbor International Airport in Phoenix, Arizona and Lincoln Municipal Airport in Lincoln, Nebraska. System Advisor Model software which has been developed by National Renewable Energy Laboratory in Golden, Colorado (USA) has been employed to conduct simulations. Certain suggestions and recommendations are made based on the results of comparative analysis of three different kinds of solar cell models for two different locations. It is expected that this work will provide pertinent references for researchers in the field of renewable energy, in particular, solar energy, for carrying out simulation analysis for future energy needs.**

Keywords-Capacity factor; energy yield; performance ratio; renewable energy; solar cell; system advisor model

I. INTRODUCTION

Due to ever increasing consumption of conventional energy sources which include fossil fuels like coal, natural gas and oil, there is an urgent need to move towards alternative sources of energy [1]. Solar energy is one of the best sources of renewable energy. If utilized appropriately, it can benefit the energy sector significantly. This paper shall discuss three different solar cell models to carry out analysis of two different locations in USA. The software used to carry out the required simulations is System Advisor Model (SAM). Although the software provides the user to select from a variety of locations around the world, this paper selects two locations within the same country (USA) for the ease of drawing out conclusions and maintain uniformity.

II. SYSTEM ADVISOR MODEL BACKGROUND

SAM was originally called the “Solar Advisor Model”. This software was first developed by the National Renewable Energy Laboratory in collaboration with Sandia National Laboratories in 2005 for internal use by the U.S. Department of Energy’s Solar Energy Technologies Program in its systems-based analysis of solar technology improvement opportunities within the program. National Renewable Energy Laboratory (NREL) released the first public version in August 2007. This permitted solar energy experts to examine photovoltaic (PV) systems in depth using financial and business models. In 2010, the software was renamed to “System Advisor Model” to reflect the incorporation technologies other than solar system.

In short, SAM is a performance and financial model created to enable decision making for researchers involved in the field of renewable energy, especially wind and solar energy. Performance predictions and estimating price of energy for grid-connected power projects based on installation and operating expenses and system design factors that the users specify as inputs to the model can be found out using SAM [2-3].

This paper utilizes Single ownership Power Purchase Agreement (PPA) utility as financial model and for performance model, three different solar models (PV Watts, PV Detailed and PV High Concentration) have been used for two different locations i.e., Phoenix (Arizona) and Lincoln (Nebraska). These settings are shown in Appendix (Figs. A1 and A2).

III. CASE I: PHOENIX, ARIZONA (USA)

Firstly, PV watts model is selected as performance model for analysis. Financial model selected is single ownership utility PPA. Location selected is Phoenix, Arizona. The relevant data such as average temperature, average wind speed, sunlight intensity etc. is automatically loaded from the software using default values. The simulation is run by clicking the “Simulate” option on the software toolbar. The following sections demonstrate the results obtained after running simulations.

A. PV Watts Case

The summary for this case is shown in Fig. 1.

Metric	Value
Annual energy (year 1)	34,813,108 kWh
Capacity factor (year 1)	19.9%
Energy yield (year 1)	1,741 kWh/kW
PPA price (year 1)	9.03 ¢/kWh
PPA price escalation	1.00 %/year
Levelized PPA price (nominal)	9.80 ¢/kWh
Levelized PPA price (real)	7.75 ¢/kWh
Levelized COE (nominal)	9.21 ¢/kWh
Levelized COE (real)	7.29 ¢/kWh
Net present value	$2,056,276
Internal rate of return (IRR)	11.00 %
Year IRR is achieved	20
IRR at end of project	12.85 %
Net capital cost	$30,892,436
Equity	$14,341,978
Size of debt	$16,550,457

Figure 1. Summary for PV Watts case (Case I: Phoenix, Arizona, USA)

Graphs for monthly and annual energy production are shown in Figs. 2 and 3 respectively. Fig. 4 shows cash flows.

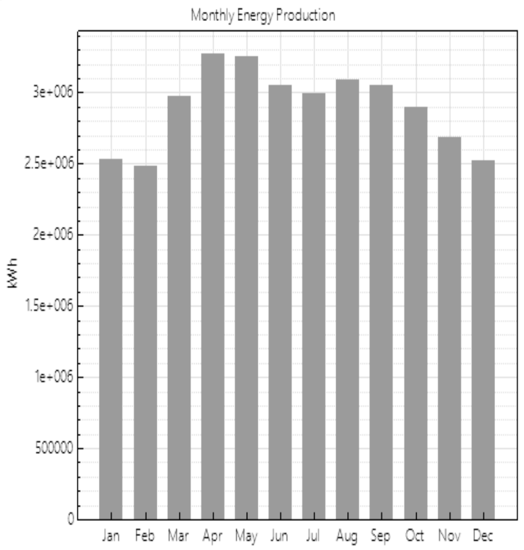

Figure 2. Monthly energy production (PV Watts Case, Case I: Phoenix, Arizona, USA)

B. PV Detailed Case

The summary for this case is shown in Fig. 5. Figs. 6, 7, 8 display monthly energy production, annual energy production and cash flows, respectively.

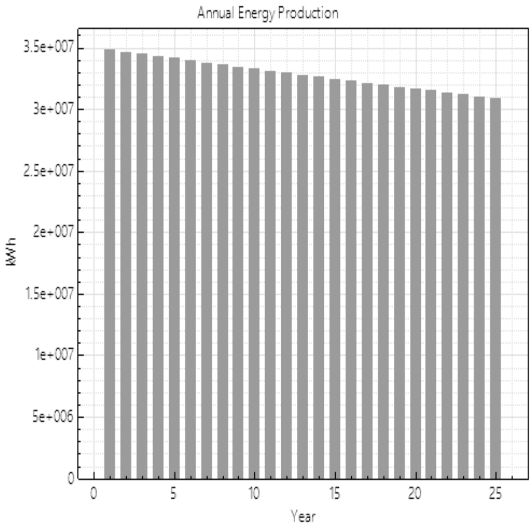

Figure 3. Annual energy production (PV Watts Case, Case I: Phoenix, Arizona, USA)

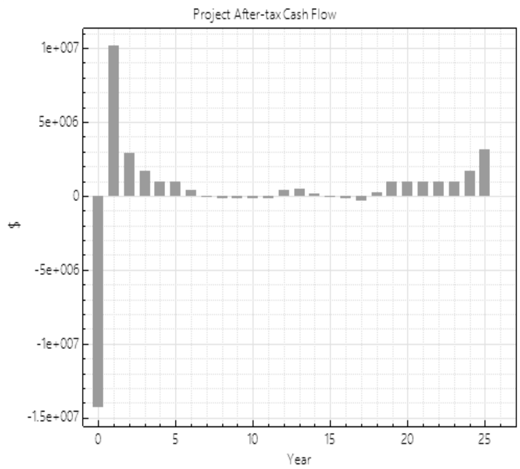

Figure 4. Cash flows (PV Watts Case, Case I: Phoenix, Arizona, USA)

Metric	Value
Annual energy (year 1)	37,246,396 kWh
Capacity factor (year 1)	21.3%
Energy yield (year 1)	1,863 kWh/kW
Performance ratio (year 1)	0.78
Battery efficiency	0.00%
PPA price (year 1)	8.44 ¢/kWh
PPA price escalation	1.00 %/year
Levelized PPA price (nominal)	9.15 ¢/kWh
Levelized PPA price (real)	7.24 ¢/kWh
Levelized COE (nominal)	8.61 ¢/kWh
Levelized COE (real)	6.81 ¢/kWh
Net present value	$2,055,989
Internal rate of return (IRR)	11.00 %
Year IRR is achieved	20
IRR at end of project	12.85 %
Net capital cost	$30,888,126
Equity	$14,339,980
Size of debt	$16,548,146

Figure 5. Summary for PV detailed case (Case I: Phoenix, Arizona, USA)

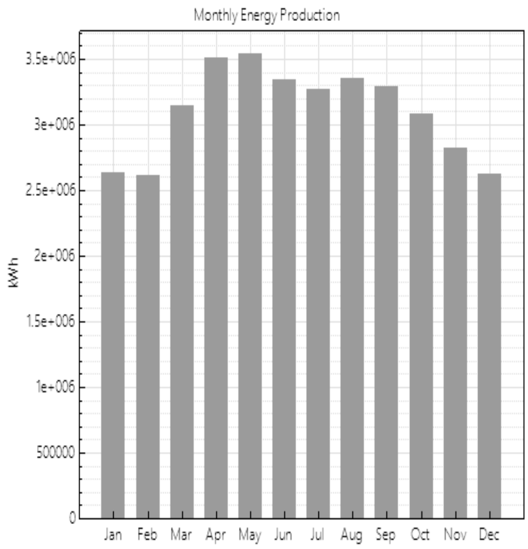

Figure 6. Monthly energy production (PV Detailed Case, Case I: Phoenix, Arizona, USA)

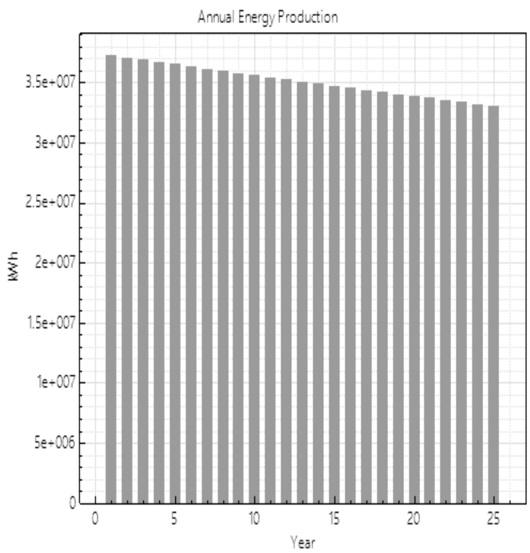

Figure 7. Annual energy production (PV Detailed Case, Case I: Phoenix, Arizona, USA)

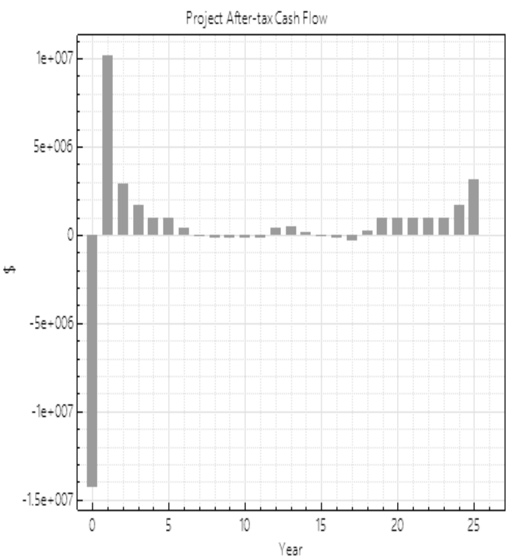

Figure 8. Cash flows (PV Detailed Case, Case I: Phoenix, Arizona, USA)

C. PV High Concentration Case

Summary for this case is shown in Fig. 9.

Metric	Value
Annual energy (year 1)	16,616,499 kWh
Capacity factor (year 1)	22.6%
PPA price (year 1)	14.53 ¢/kWh
PPA price escalation	1.00 %/year
Levelized PPA price (nominal)	15.76 ¢/kWh
Levelized PPA price (real)	12.47 ¢/kWh
Levelized COE (nominal)	14.63 ¢/kWh
Levelized COE (real)	11.57 ¢/kWh
Net present value	$1,915,718
Internal rate of return (IRR)	11.00 %
Year IRR is achieved	20
IRR at end of project	12.66 %
Net capital cost	$29,103,460
Equity	$14,078,430
Size of debt	$15,025,030

Figure 9. Summary for PV high concentration case (Case I: Phoenix, Arizona, USA)

Monthly energy production, annual energy production and cash flows are shown in Figs. 10, 11 and 12, respectively.

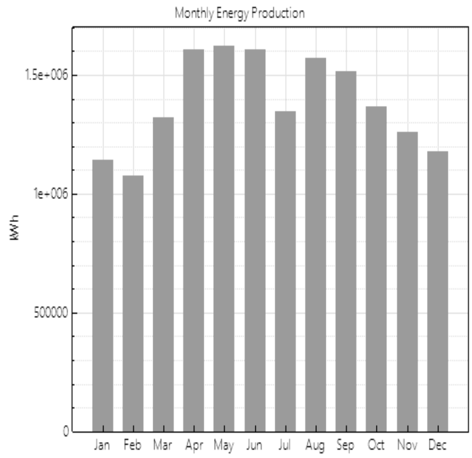

Figure10. Monthly energy production (PV High Concentration Case, Case I: Phoenix, Arizona, USA)

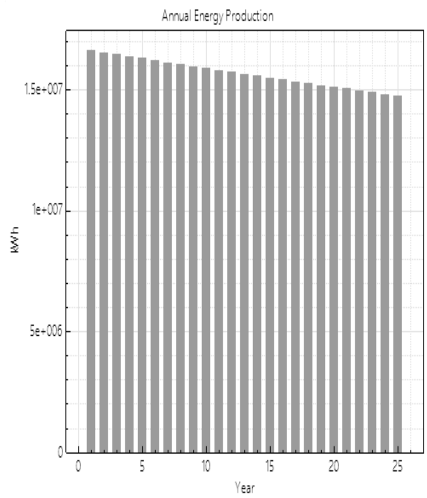

Figure 11. Annual energy production (PV High Concentration Case, Case I: Phoenix, Arizona, USA)

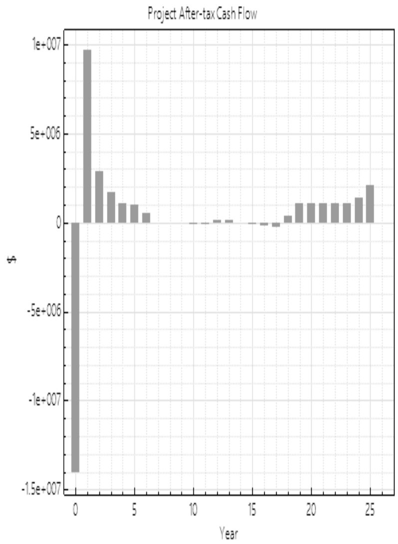

Figure 12. Cash flows (PV High Concentration Case, Case I: Phoenix, Arizona, USA)

D. Discussion

It is important to realize the reasons for low-capacity factor. There are many reasons for a solar plant to have a capacity factor less than 100%. The primary reason is that the plant may be out of service due to routine maintenance, or it may be working at abridged output for some period owing to equipment failures. This also takes into consideration the idle capacity of base load power plants. Base load plants possess minimum costs per unit of electricity because they are intended to have highest efficacy and are controlled continually at large powers.

The second reason for a capacity factor less than the ideal 100% is that output is abridged because there is no requirement of electricity, or the cost of electricity is too less to make output financially beneficial. This considers much of the idle capacity of peaking power plants and load following power plants. Peaking plants may function only for a few times during the entire year. Their electricity price is comparatively costly.

The third and quite critical reason is that a plant may not contain sufficient fuel to function all the time. Fossil fuel generating plants with limited fuels supplies come in this category. The accessibility of their “fuel” restricts capacity factor of solar arrays and wind turbines. By “fuel”, it is meant sunlight and wind [4-5].

In terms of annual energy production, “PV detailed” has the highest value (about 37,000,000 kWh). For all three cases, April and May are the months where maximum monthly energy is produced, however, in case of PV high concentration, the value is the lowest (about 16,00,000 kWh) as compared to other two cases (around 35,000,00 kWh)

It is essential to understand positive and negative cash flows. Positive operational cash flow implies that the industry can fully fund their functional abilities from sales. When operational cash flow is negative, cash flow from financing activities must make up for the operational cash deficit or the industry will rapidly run out of the cash displayed on its balance sheet. In simple words, negative cash flow means that the business is losing money. This kind of cash flow reflects poor timing of income and expenses. Therefore, to gain profit and put the company in financial advantage, it is important to attain positive cash flows. Fig. 13 depicts this situation.

Figure 13. A simple pictorial view of positive cash flow

As far as cash flows are concerned, “PV watts” and “PV detailed” have negative cash flows in the years 8-11. This is a major drawback for them. PV high concentration has neither positive nor negative cash flows during these years. However, after these years, PV watts and PV detailed more positive cash flows compared to ‘High concentration’ case.

LCOE is the lowest (6.91 cents/kWh) for ‘PV detailed’ model but highest (11.57 cents/kWh) for ‘PV high concentration’ model. Moreover, similar trend is observed for PPA Price. It is lowest (7.35 cents/kWh) for PV detailed model and highest (12.47 cents/kWh) for PV high concentration model. Hence, comparing the three cases for Phoenix location, it is recommended to use PV detailed model as it offers least cost of electricity. Moreover, its capacity factor is also higher than the PV watts model.

IV. CASE II: LINCOLN, NEBRASKA (USA)

A. PV Watts Case

The summary for this case is shown in Fig. 14.

Metric	Value
Annual energy (year 1)	27,332,612 kWh
Capacity factor (year 1)	15.6%
Energy yield (year 1)	1,367 kWh/kW
PPA price (year 1)	11.50 ¢/kWh
PPA price escalation	1.00 %/year
Levelized PPA price (nominal)	12.48 ¢/kWh
Levelized PPA price (real)	9.87 ¢/kWh
Levelized COE (nominal)	11.73 ¢/kWh
Levelized COE (real)	9.28 ¢/kWh
Net present value	$2,056,276
Internal rate of return (IRR)	11.00 %
Year IRR is achieved	20
IRR at end of project	12.85 %
Net capital cost	$30,892,436
Equity	$14,341,978
Size of debt	$16,550,457

Figure 14. Summary for PV Watts case (Case II: Lincoln, Nebraska, USA)

Graphs for monthly and annual energy production are shown in Figs. 15 and 16, respectively. Fig. 17 shows cash flows.

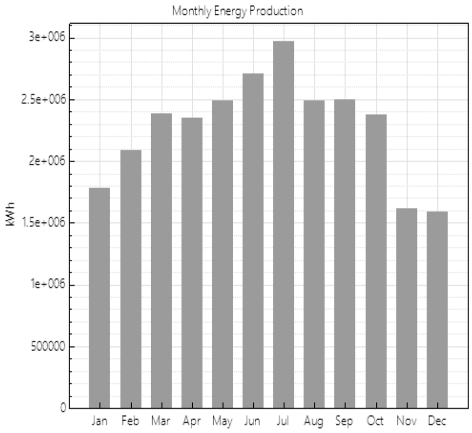

Figure 15. Monthly energy production (PV Watts Case, Case II: Lincoln, Nebraska, USA)

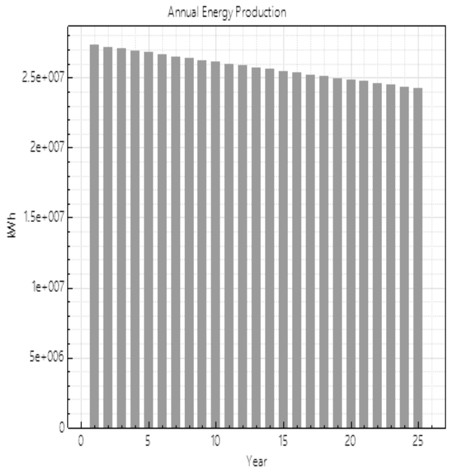

Figure 16. Annual energy production (PV Watts Case, Case II: Lincoln, Nebraska, USA)

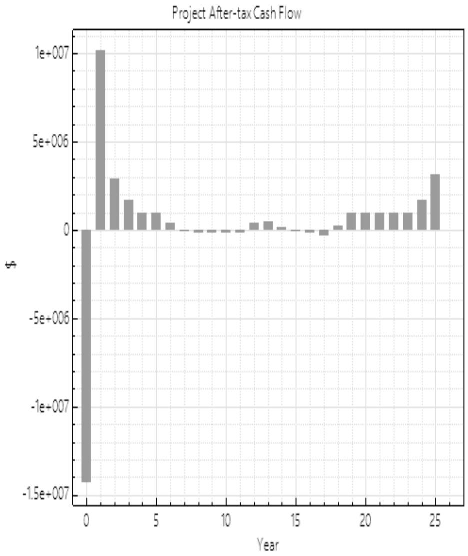

Figure 17. Cash flows (PV Watts Case, Case II: Lincoln, Nebraska, USA)

B. PV Detailed Case

The summary for this case is shown in Fig. 18. Figs. 19, 20 and 21 show monthly energy production, annual energy production and cash flows respectively.

Metric	Value
Annual energy (year 1)	28,524,230 kWh
Capacity factor (year 1)	16.3%
Energy yield (year 1)	1,426 kWh/kW
Performance ratio (year 1)	0.83
Battery efficiency	0.00%
PPA price (year 1)	11.18 ¢/kWh
PPA price escalation	1.00 %/year
Levelized PPA price (nominal)	12.13 ¢/kWh
Levelized PPA price (real)	9.59 ¢/kWh
Levelized COE (nominal)	11.40 ¢/kWh
Levelized COE (real)	9.02 ¢/kWh
Net present value	$2,099,661
Internal rate of return (IRR)	11.00 %
Year IRR is achieved	20
IRR at end of project	12.85 %
Net capital cost	$31,557,726
Equity	$14,674,361
Size of debt	$16,883,364

Figure 18. Summary for PV detailed case (Case II: Lincoln, Nebraska, USA)

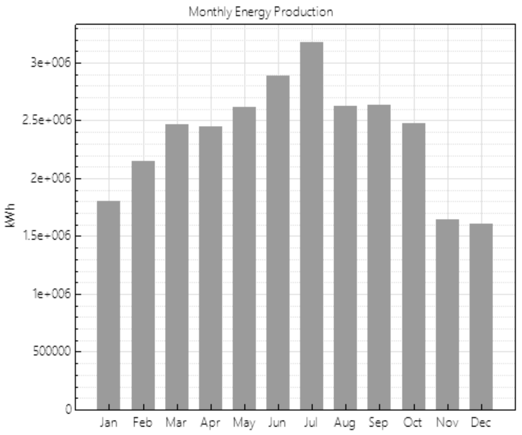

Figure 19. Monthly energy production (PV Detailed Case, Case II: Lincoln, Nebraska, USA)

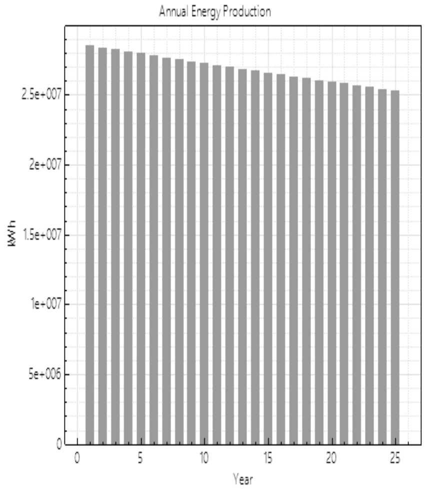

Figure 20. Annual energy production (PV Detailed Case, Case II: Lincoln, Nebraska, USA)

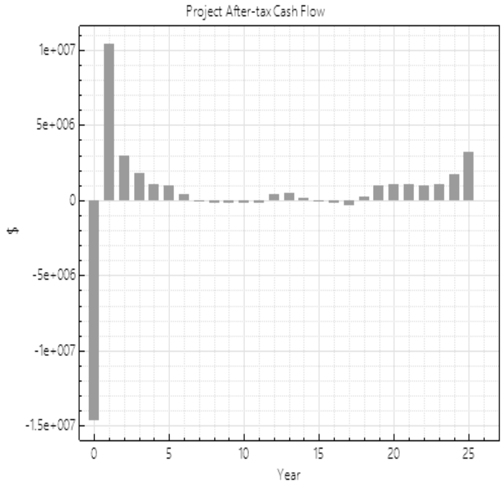

Figure 21. Cash flows (PV Detailed Case, Case II: Lincoln, Nebraska, USA)

C. PV High Concentration Case

The Summary for this case is shown in Fig. 22. Monthly energy production, annual energy production and cash flows are shown in Figs. 23, 24 and 25 respectively.

Metric	Value
Annual energy (year 1)	9,750,089 kWh
Capacity factor (year 1)	13.3%
PPA price (year 1)	24.45 ¢/kWh
PPA price escalation	1.00 %/year
Levelized PPA price (nominal)	26.52 ¢/kWh
Levelized PPA price (real)	20.97 ¢/kWh
Levelized COE (nominal)	24.61 ¢/kWh
Levelized COE (real)	19.46 ¢/kWh
Net present value	$1,885,566
Internal rate of return (IRR)	11.00 %
Year IRR is achieved	20
IRR at end of project	12.66 %
Net capital cost	$28,641,156
Equity	$13,847,567
Size of debt	$14,793,589

Figure 22. Summary for PV high concentration case (Case II: Lincoln, Nebraska, USA)

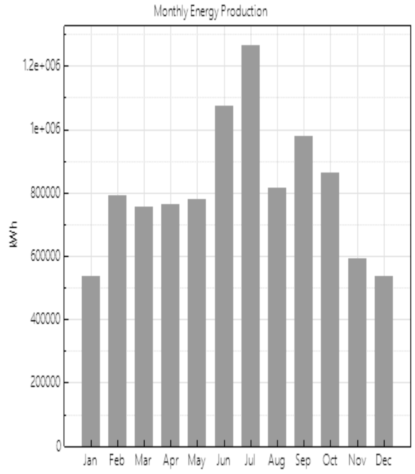

Figure 23. Monthly energy production (PV High Concentration Case, Case II: Lincoln, Nebraska, USA)

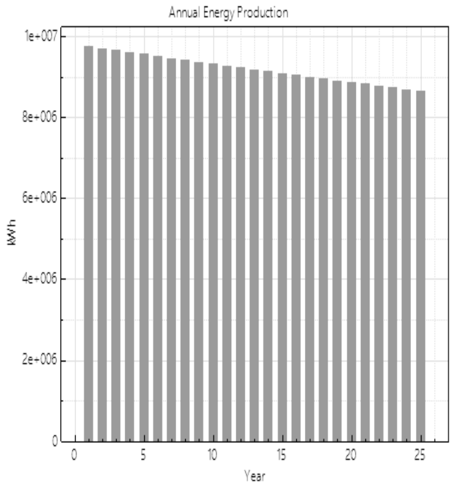

Figure 24. Annual Energy production (PV High Concentration Case, Case II: Lincoln, Nebraska, USA)

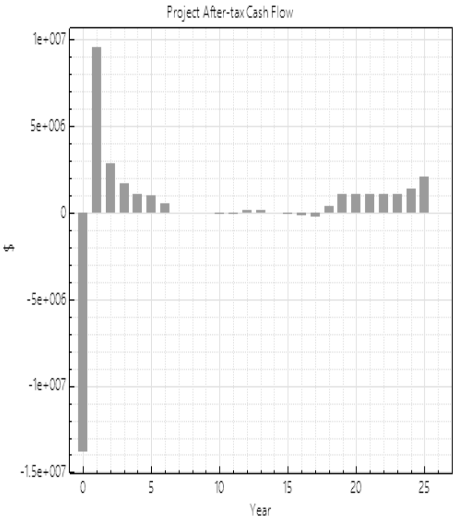

Figure 25. Cash flows (PV High Concentration Case, Case II: Lincoln, Nebraska, USA)

D. Discussion

With the change of location from Phoenix to Lincoln, we observe the "shift" in capacity factor. Capacity factor is now the lowest (13.3%) in case of "PV High concentration" while it is at its maximum (16.3%) in "PV detailed" case.

Monthly energy production is maximum in the month of July and minimum in the month of December for all three cases. This is obvious since in December, temperature is relatively low, and many days are present with dense cloud covers and less sunshine. The value of maximum monthly energy (for July) is greatest (about 3.3 e6 kWh) for PV detailed case and lowest (about 1.3e6 kWh) for High concentration case. Annual energy production is lowest (about 97,00000 kWh) in 'High concentration PV' as the capacity factor is low.

Real Levelized Cost of Electricity (LCOE) is lowest (9.02 cents/kWh) for PV detailed model and highest (19.46 cents/kWh) for 'high concentration PV' model. Same trends follow for Levelized PPA price. It is lowest (9.59 cents/kWh) for PV detailed model and highest (20.97 cents/kWh) for PV High concentration model.

In short, comparing the three cases for Lincoln airport location, it is suggested to use PV detailed model as it has highest capacity factor amongst all cases. Moreover, its overall annual energy production is largest (about 28,000,000 kWh) and LCOE is cheaper.

V. SUMMARY OF SOLAR MODELS

A. PV Watts Model

In PV watts model, annual energy production is greater (about 34000000 kWh) for Phoenix, AZ than Lincoln, NE (about 27000000 kWh). This is since capacity factor for Phoenix location is greater than that of Lincoln. This is because Phoenix receives more sunlight as compared to Lincoln. According to National Climatic Data Centre and National Renewable Energy Laboratory [6-7], Phoenix has about 3872 Hours of Sun and 211 clear days on the average as compared to Lincoln which has only 117 clear days on average. Moreover, for Phoenix, the LCOE is less (7.29 cents/kWh) as compared with Lincoln (9.28 cents/kWh). Also, Levelized PPA price is lower for Phoenix.

B. PV Detailed Model

For PV detailed model, annual energy production is again greater for Phoenix, reason being the high capacity factor. LCOE is also cheaper (6.91 cents/kWh) for Phoenix compared to Lincoln (9.02 cents/kWh).

C. PV High Concentration Model

For this case, annual energy production is again greater for Phoenix, reason being the high-capacity factor. LCOE is also cheaper (11.57 cents/kWh) for Phoenix compared to Lincoln (19.46 cents/kWh). PPA price for Phoenix is lesser than Lincoln by 8.5 cents/kWh.

CONCLUSION AND FUTURE WORK

This paper used three different solar cell models for two distinct locations in USA. The software used was SAM. On the basis of results obtained, it was concluded that PV detailed model should be used in Phoenix (Arizona) as it offers least cost of electricity. Moreover, its capacity factor is also higher than the PV watts model. Similarly, by comparing the three cases for Lincoln airport location, it is suggested to again use PV detailed model as it has highest capacity factor amongst all cases. Moreover, its overall annual energy production is largest (about 28,000,000 kWh) and LCOE is cheaper. As a future research direction, these models can be tested on different locations of a particular State in USA, say, California or Texas, where there is ample amount of sunshine and financial model can be changed to residential or commercial instead of PPA single owner utility. As reverse leakage currents due to radiative recombination play a very substantial role in the performance of a solar cell, they can be incorporated for future studies.

Also, as a future work, the proposed simulations can be modified considering real values, in accordance with the desired scenarios. Further research can be conducted to observe if the powers obtained can be installed in the locations analyzed (including various factors such as what area it occupies, what is the shading coefficient, the effect of temperature on the energy obtained, etc.)

This study provided an analysis for different solar cell models that can be an offset for researchers in the domain of power system integration with solar systems. Contemporary research [8-15] reveals that there is a lot of work which needs to be done in research domain related to solar cells.

APPENDIX

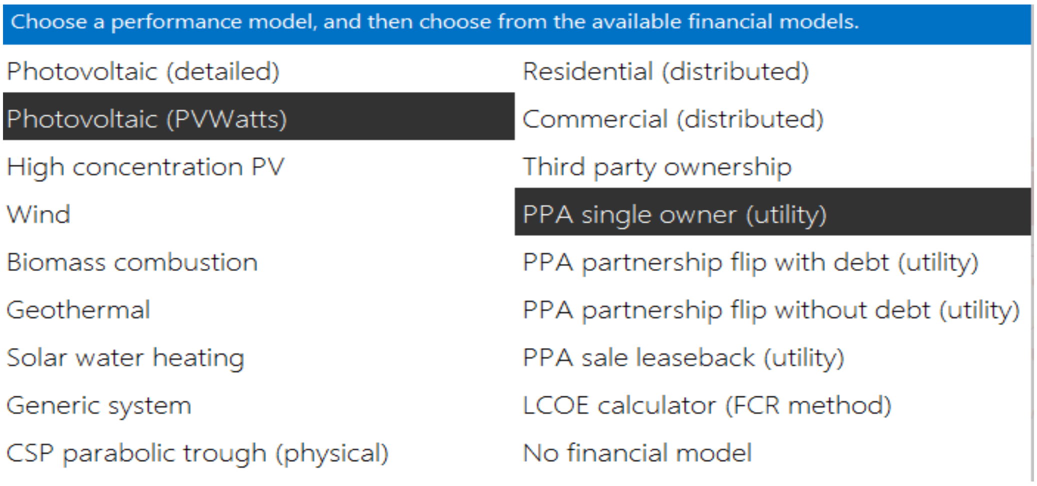

Figure A1. Selecting performance and financial Models in SAM

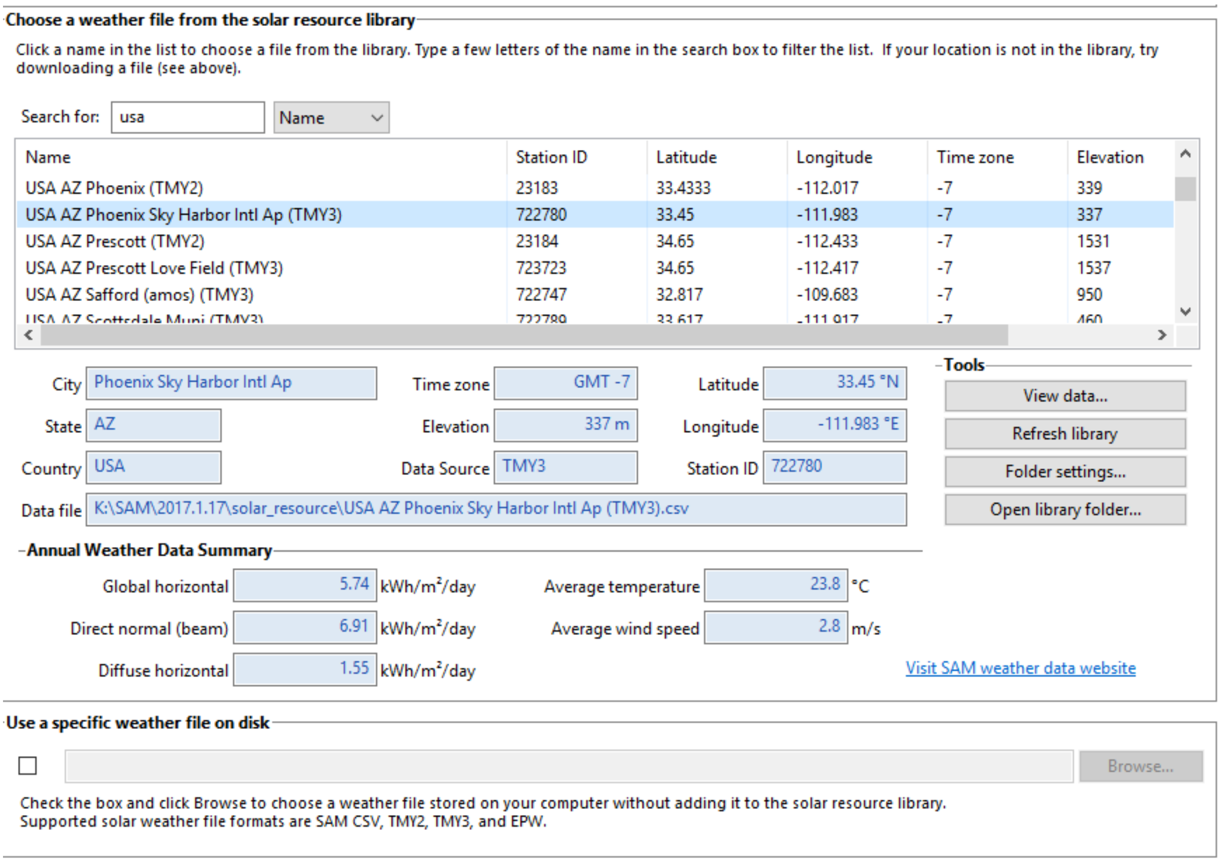

Figure A2. Selecting desired location for conducting simulations in SAM

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