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A Multi-Stage Approach to Assessing the Echo-Tech Feasibility of a Hybrid SAM-CREST Model for Solar PV Power Plants in Maryland, USA

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Abstract: Maryland is actively working towards doubling its Renewable Portfolio Standard (RPS) target, aiming to increase the share of renewable energy from 25% by 2020 to 50% by 2030. Furthermore, Maryland stands out as a state that strongly supports solar initiatives, offering incentives and specialized programs to assist residents in adopting solar energy solutions. The paper presents a multi-stage approach: Stage 1—Location Selection Process, Stage 2—Technical Feasibility Study, and Stage 3—Economical Feasibility Study. In Stage 1, the study focuses on three potential solar farm locations in Maryland: Westover, Princess Anne, and Eden. Stages 2 and 3 involve a feasibility assessment with detailed technical analysis using the NREL System Advisor Model (SAM) and PVWatts to determine monthly power to the grid and Energy Yield. Subsequently, economic feasibility is assessed using the NREL Clean Renewable Energy Estimation Simulation Tool (CREST), focusing on competitive levelized costs of energy (LCOE), payback time, and cumulative cash flows. Results indicate that all three locations exhibit promising solar irradiance levels, system outputs, and potential energy yields. Due to high solar irradiation, the Westover area has the highest energy yield at 1583.13 kWh/kW, while Princess Anne boasts the highest system output at 333.59 GWh. The economic evaluation suggests that all three locations become profitable within a two-year payback time, with competitive levelized costs of energy (LCOE). Westover emerges as the most cost-effective option at 5.99 cents/kWh, attributed to its higher solar irradiation values and energy yield compared to Princess Anne and Eden. Cumulative cash flows provide insights into long-term profitability, with Princess Anne, MD, having the highest Cumulative Cash Flow over 25 years at $183,383,304. By evaluating technical and economic aspects, this feasibility study offers quantitative insights to guide decision-making for the installation of Solar PV, considering both technological and economic feasibility.

Keywords: renewable energy; solar photovoltaic (PV); feasibility study; Maryland; system output; NREL System Advisor Model (SAM); PVWatts; Clean Renewable Energy Estimation Simulation Tool (CREST); levelized costs of energy (LCOE); payback time; cumulative cash flows

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1. Introduction

The United States is currently experiencing a substantial surge in demand for renewable energy sources, primarily driven by the need to address escalating environmental concerns, combat climate change, and reduce dependence on finite fossil fuels [1–7]. The International Energy Agency (IEA) reported that in 2019, renewable energy accounted for approximately 11% of the total U.S. energy consumption, signifying a notable shift towards sustainable alternatives [8]. Furthermore, the devastating impacts of the COVID-19 crisis underscored the critical importance of cleaner and more resilient energy systems.

Within the spectrum of renewable energy solutions, solar photovoltaic (PV) power has emerged as a frontrunner in addressing climate change and bolstering alternative energy adoption across the USA [7,9,10]. The International Renewable Energy Agency (IRENA) reported that in 2018, the levelized cost of electricity (LCOE) for utility-scale solar PV in the United States plummeted to just 3.7 cents per kilowatt-hour (kWh), underlining its economic viability and environmental benefits [11]. Solar PV systems significantly reduce greenhouse gas emissions and have a minimal environmental footprint, making them a cornerstone of sustainable energy generation [11,12].

Within this context, Maryland has emerged as a vanguard in the adoption of renewable energy, particularly evident in its robust embrace of solar PV installations. Maryland, as a microcosm of the broader U.S. renewable energy landscape, has implemented a comprehensive framework of incentives, strategic initiatives, policies, and trends to promote solar PV adoption [13,14]. The Maryland Energy Administration (MEA) administers an array of programs, including net metering, tax credits, and renewable portfolio standards, to stimulate solar PV installations across the state.

This study undertakes a comprehensive exploration into the viability of solar PV ventures in Maryland, employing analytical instruments such as the System Advisor Model (SAM) featuring PVWatts and the Clean Renewable Energy Estimation Simulation Tool (CREST) [15–17]. Developed by the National Renewable Energy Laboratory (NREL), SAM empowers renewable energy professionals by providing a comprehensive techno-economic analysis of renewable energy systems [18]. CREST, another NREL creation, facilitates the assessment of project economics and the determination of energy costs, contributing to informed decision-making [17,18]. Through a meticulous evaluation encompassing technical, economic, and environmental dimensions, this research provides intricate quantitative perspectives to inform decision formulation [18].

Maryland's steadfast commitment to Solar Energy is conspicuously underscored by its policy frameworks and strategic orientations, thereby rendering it an exemplary subject for this investigation. The present paper unfolds a multi-phased methodology, commencing with the meticulous selection of suitable locales predicated upon parameters encompassing topography, solar irradiance, expenditure, and proximity to load distribution centers. The ensuing feasibility appraisal entails an exhaustive technical analysis leveraging SAM and PVWatts to compute energy output potential. Subsequently, the economic tenability is scrutinized via CREST, entailing considerations spanning operational and maintenance outlays, tax incentives, and potential avenues for financing.

2. Methodology

2.1. Stage 1. Location Selection Process

Maryland, a state that consumes more energy than it generates, faces a situation where it currently consumes around 5.5 times the energy it produces [19]. In 2021, Maryland's total electricity net generation was predominantly fueled by nuclear energy and natural gas, contributing to 73% of the state's energy mix [20]. On the renewable energy front, encompassing small-scale installations (less than 1 megawatt) and utility-scale facilities (1 megawatt or larger), Maryland sourced approximately 12% of its in-state electricity from these sustainable sources during the same year. Notably, roughly 4.8% of Maryland's electricity is generated from solar energy, with residential solar contributing about 60% of this generation [20,21]. This scenario creates a demand and market for utility-scale solar energy within the state. Before delving into the analysis of Solar PV feasibility and profitability in Maryland, three prime areas—Westover, Eden, and Princess Anne—were chosen for investigation, as depicted in Figure 1. The optimal location for a solar farm involves numerous considerations beyond just geographic factors; upfront costs, operational and maintenance expenses, taxes, and incentives, among others, must all be factored in. This paper particularly emphasizes four critical criteria, as enumerated in Table 1.

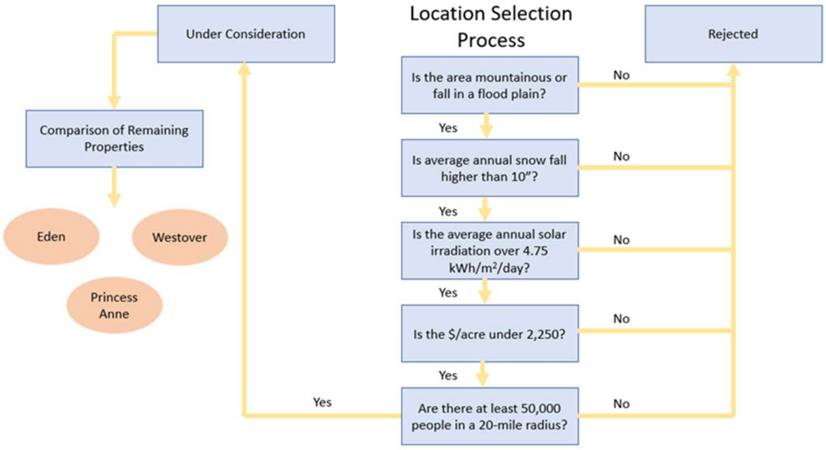


Figure 1. Flowchart illustrating the location selection process.

Table 1. Four Criteria for the location selection process.

Criteria	Definition
Terrain	Encompasses geographical features relevant to solar farm construction, considering weather conditions, proximity to towns, flood plains, and more.
Solar Irradiation	Represents kWh generated per square meter of paneling daily. Higher irradiance indicates greater potential power output.
Property Cost and Size	Encompasses average property costs, tax incentives, upfront expenses, and more.
Proximity to Load	Reflects the distance from the solar farm to load centers, minimizing energy loss during transmission. Zoning and property costs also factor in.

Consideration (1): Terrain. Maryland is a state with a variety of terrains, all of which have different impacts and implications when it comes to the construction of a solar farm. The Northwestern part of the state is part of Appalachia, and the resulting terrain would result in additional difficulties when building. There are also many bodies of water within the state. Proximity to rivers and lakes is considered to prevent flooding. Proximity to the ocean is taken into consideration for the same reason. Plus, solar panels suffer system losses due to soiling, shading, snow, dust, etc., and overtime, salt can also affect the efficiency of solar panels. The southern parts of the state were also given heavier consideration because they receive less accumulative snowfall, which also affects the efficiency of the panels. Topographical maps, Google Earth, and PVWatts were used to determine the suitability of the properties.

Consideration (2): Solar Irradiation. Maryland, depending on the part of the state, solar irradiance ranges from 4–5 kWh/m^2/day when considering only fixed solar panels [21,22]. For this study, we only looked at the areas that had averages of 4.75 kWh/m^2/day. However, when analyzing using two-axis tracking panels, the numbers from the final three locations fell to around 6.85 kWh/m^2/day annually. The solar irradiation data were pulled from the National Renewable Energy Laboratory (NREL) using the organization's vast database of solar data Excel files and PVWatts tool [15].

Consideration (3): Property Cost and Size. Given the preferable terrain and solar irradiation conditions in the southern parts, the focus shifted there to potential solar farm locations. Unlike a previous study's minimum acreage threshold of 500 acres, Maryland's higher land prices and smaller size led to a shift in focus to properties with over 200 acres. The property's cost was a key factor, with areas around Maryland's peninsula emerging as the cost-effective options.

Consideration (4): Proximity to Load. Maryland's denser population compared to Kentucky led to a 20-mile radius containing at least 50,000 individuals being the criterion for considering a location [9]. Closeness to the load minimizes energy loss during transmission and reduces infrastructure needs. However, being too close to metropolitan areas can lead to zoning issues and higher property costs. Balancing these factors, the optimal choices were identified as Eden, Westover, and Princess Anne.

2.2. Stage 2. Technical Feasibility Study

The NREL's System Advisor Model (SAM) functions as an open-source techno-economic software tool, providing crucial assistance to stakeholders in the renewable energy domain for well-informed decision-making. The integration of the System Advisor Model (SAM) with PVWatts forms an easily accessible resource, enabling thorough performance and financial analyses for renewable energy systems, as illustrated in Figure 2. In this study, we employed the NREL's System Advisor Model (SAM) alongside PVWatts. In our research, we utilized the NREL's System Advisor Model (SAM) in conjunction with PVWatts, allowing for the determination of average monthly outputs as AC Power Outputs [16,23].

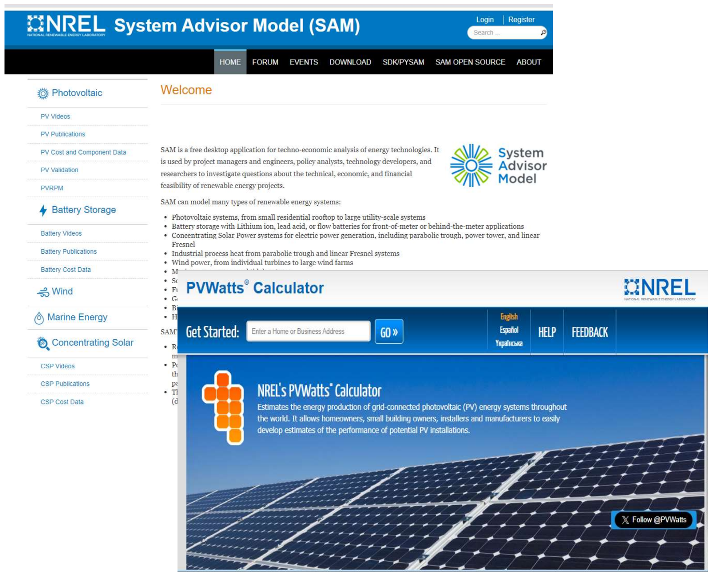


Figure 2. SAM and PVWatts Main Window [15–18,23].

For this study, The output is the system AC Power output (P_{gen}), which represents the electricity generated by the Solar PV power system and transmitted to the electrical power grid [16,23]. The power (P_{gen}) takes into account various losses and adjustments, including Total AC power loss (L_{ac}: %) and curtailment and availability losses (L_{adjust}: %). The formulation for defining the system AC power output is articulated as follows:

$$\boldsymbol{P_{gen} = N_{inv} P_{ac} \left(1 - \frac{L_{ac}}{100}\right)\left(1 - \frac{L_{adjust}}{100}\right)}$$

Here, N_{inv} represents the number of inverters connected to the grid side, and P_{ac} is the AC output of a single inverter.

- Inverter AC Output (P_{ac})

SAM employs the Blair 2013 inverter model to compute both the aggregate AC power output of all inverters in the system and the specific AC output of an individual inverter. Furthermore:

(a) The Inverter CEC Database, also referred to as the Sandia inverter model, is an empirical model utilizing manufacturer specifications with empirically derived coefficients C0, C1, C2, and C3 (King 2007) This model draws parameters from a database managed by the California Energy Commission (Go Solar California 2014) as shown in the Table 2.

Table 2. Parameters of the Inputs for SAM AC System Outputs.

Symbol	Inputs Descriptions (Unit)
$\boldsymbol{C_0}$	Curvature between AC power and DC power (1/W)
$\boldsymbol{C_1}$	Coefficient of Pdc,0 variation with DC input voltage (1/V)
$\boldsymbol{C_2}$	Coefficient of Pso variation with DC input voltage (1/V)
$\boldsymbol{C_3}$	Coefficient of C0 variation with DC input voltage (1/V)
$\boldsymbol{V_{dc}}$	DC String Voltage (V)
$\boldsymbol{V_{ac,0}}$	Nominal AC voltage (V)
$\boldsymbol{P_{dc,0}}$	Maximum DC power (W)
$\boldsymbol{P_{dc}}$	Array power (DC) (kW)

(b) The Inverter Datasheet implements the Sandia inverter model by setting the empirical coefficients' values to zero, enabling the modeling of the inverter based solely on manufacturer specifications.

(c) The Inverter Part Load Curve is an NREL-developed SAM model employing a table of efficiency values at various inverter load levels to depict the inverter's performance.

These inverter models calculate the DC-to-AC power conversion efficiency at rated and part-load operating power, but they do not explicitly consider temperature effects on inverter performance or the impact of power factor control or grid outages.

The parameters for the Sandia inverter model are defined as follows:

$$\begin{aligned} \mathrm{A} &= \boldsymbol{P_{dc,0}}[\mathbf{1} + \boldsymbol{C_1}(\boldsymbol{V_{dc}} - \boldsymbol{V_{dc,0}})] \\ \mathrm{B} &= \boldsymbol{P_{s,0}}[\mathbf{1} + \boldsymbol{C_2}(\boldsymbol{V_{dc}} - \boldsymbol{V_{dc,0}})] \\ \mathrm{C} &= \boldsymbol{C_0}[\mathbf{1} + \boldsymbol{C_3}(\boldsymbol{V_{dc}} - \boldsymbol{V_{dc,0}})] \end{aligned}$$

The Sandia inverter model equation is given by the following:

$$P_{ac} = \left[\frac{P_{ac,0}}{A-B} - C(A-B)\right](P_{dc} - B) + C(P_{dc} - B)^2$$

- AC Power Losses (L_{ac})

The AC Power Losses (L_{ac}: %) in SAM encompass electrical losses on the AC side, represented by a single AC loss percentage. A SAM's model for Total AC power loss (L_{ac}: %) incorporates calculations of AC loss percentage derived from AC wiring (L_*acwiring*) and step-up transformer loss percentages (L_*transformer*) as follows:

$$L_{ac} = 100\left[1 - \left(1 - \frac{L_{transformer}}{100}\right)\left(1 - \frac{L_{acwiring}}{100}\right)\right]$$

- Curtailment and Availability Losses (L_{adjust})

Moreover, Curtailment and Availability Losses ($\boldsymbol{L_{adjust}}$) serve to account for operational losses attributed to factors beyond solar resource variations and system design, including forced, scheduled, and unplanned outages. SAM models these losses by employing an array of hourly loss values applicable to each simulation time step. The definition of curtailment and availability losses in SAM is accessible through the Edit Losses window on the Losses input page.

Following the assessment of optimal locations based on property characteristics and aforementioned considerations, the technical feasibility phase, as illustrated in Figure 3, delves into a more comprehensive analysis. While the preliminary assessment was touched upon in Stage 1, the use of SAM with PVWatts in Stage 2 provides a more detailed assessment of theoretical solar farm energy outputs. Input variables for the program were determined.

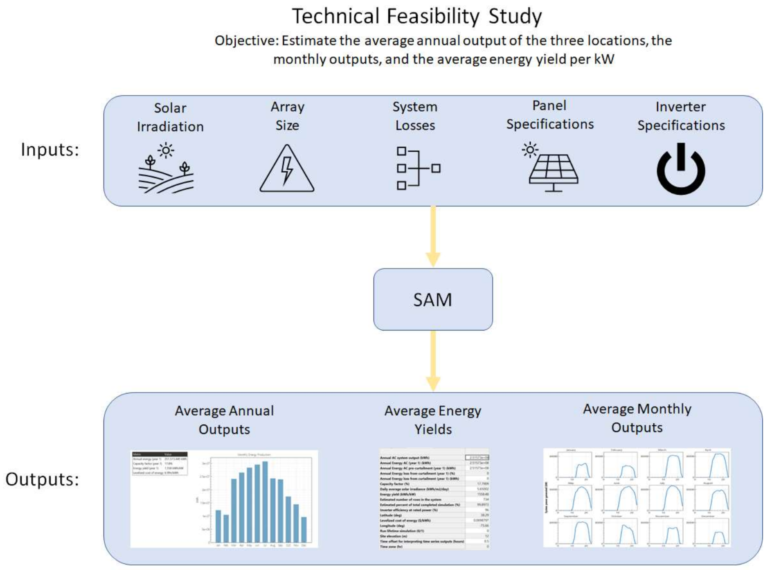


Figure 3. Flowchart depicting the technical feasibility study process [18,23].

Input (1) Solar Irradiation: This Solar Irradiation is addressed in the earlier Section 2.1. Location Selection. The Average Solar Irradiation in areas in the state represents 4.75 kWh/m^2/day. This study utilizes a data set that contains 8762 data points. Figure 4 shows a solar irradiation value (kWh/m^2/day) for every 30 min in 2021.

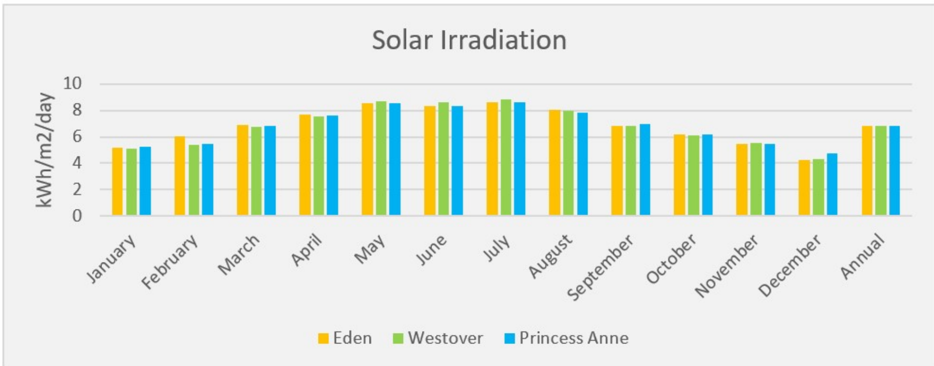


Figure 4. Solar irradiation data from the chosen three areas (Eden, Westover, and Princess Anne, MD) on a graph [22].

Input (2) Array Size: Array Size refers to the Nameplate Capacity of the solar panels that would be installed at the given location. The more complex part is determining what the theoretical Nameplate Capacity (also known as the theoretical power of a panel) would be. It is roughly estimated that approximately 2000 panels can fit on an acre of land without shading one another. Utilizing this estimate, the panel's power (300 W), and the acreage available, we determined the Array Size as shown in Table A1 of the Appendix A.

Input (3) System Losses: There are a variety of losses that can occur in the generation of solar power. Soiling Losses are losses due to soil or other debris on the panel whether this is dust, pollen, etc. In this case, the value is set to 2%. Shading Losses are losses due to lost incident solar radiation due to shadows from nearby objects or other panels. At these locations, this value is 3%. Snow Losses are losses due to snow accumulation on the panels. This specific loss varies based on the time of year. The value reaches up to 6% though. This acts on the assumption, though, that there is a concentrated effort to clear ice and snow from the panels each day. Mismatch, Wiring, and Connections Losses are all losses associated with installation or panel parts, such as wires, resistors, etc. The losses for each of these are as follows: 2%, 2%, and 0.5%. Light-Induced Degradation is caused by the degradation of the PV cells over time. In a similar vein, Age Losses are due to the aging and degradation of the panels over time. These are a few of the most important losses. A full list of losses and parameters can be found in Tables A1 and A2 of the Appendix A.

Input (4 and 5) Panel and Inverter Specifications: SAM allows users to choose a specific brand and panel if they wish to, and it will auto-fill certain parameters, such as nominal efficiency, max power, max power voltage, max power current, open current voltage, short circuit current, temperature coefficients, material, module area, etc. [23]. Users can also choose their inverter of choice from the list. This choice will auto-fill the inverter's max AC power, max DC power, power use during operation, nominal AC voltage, max DC voltage, max DC current, min MPPT DC voltage, nominal DC voltage, max MPPT DC Voltage, etc. parameters as shown in the Table A2 of the Appendix A.

2.2.1. Output (1) Average Annual Monthly Outputs [GWh]

The first output is Average Annual Output or AC System Output, which gives us a quick, easy metric to compare to the other solar farms and national averages. Also, it is called Annual Energy, and Monthly Energy refers to the number of GWh that will theoretically be produced in the named time frame. Many of the upcoming graphs will be based on these values, as shown in Figure 5. This section displays the average value for a 24 h time period during that month.

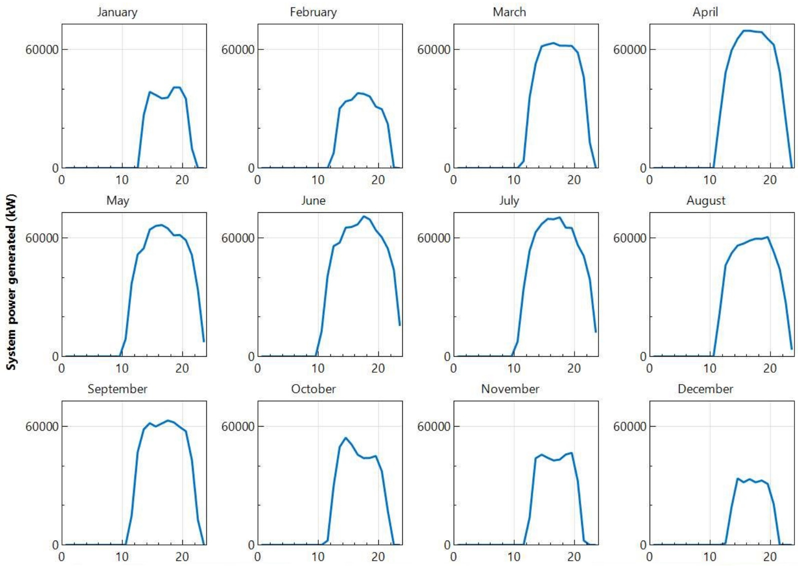


Figure 5. Example of Monthly Output in regard to kWh generated from real-time 2021 data [15].

2.2.2. Output (2) Average Energy Yields [kWh/kW]

Energy yield will be used to determine the efficiency of the farm in comparison to other locations. It is often used to help determine the financial value of an array and compare operating results from different technologies and systems. This refers to the number of kWh that are produced over a set time period per 1 kW of installed solar (referring to the nameplate generation capacity of the solar panels). For example, if one panel is rated as a 300 W panel and it produced 5 kW over a set amount of time, its energy yield would be 16.7 kWh/kW. We can view all of these singular values of SAM Modeling in Table A1 of the Appendix A.

2.3. Stage 3: Economical Feasibility Study

The Cost of Renewable Energy Spreadsheet Tool (CREST) comprises models designed to assess project economics, formulate cost-based incentives, and evaluate the impact of state and federal support structures on renewable energy [17,24]. CREST, developed by NREL, is a cash flow tool utilized to assess project economics and determine the cost of energy after the completion of the technical feasibility study. We take the generation results from the previous study, along with various financial parameters, and input these values into CREST to determine the Payback Period (in years) and Cumulative Cash Flows ($) as illustrated in Table A3 of the Appendix A. Additionally, the Levelized Cost of Energy (LCOE) ($/kWh) is derived from the System Advisor Model (SAM), as depicted in Figure 6. The necessary inputs and outputs are detailed below:

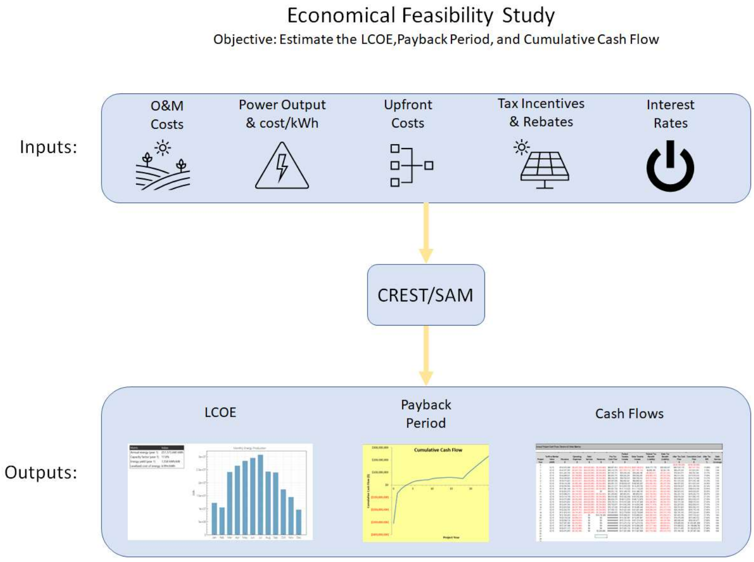


Figure 6. Flowchart outlining the economic feasibility study.

2.3.1. Input (1) Power Output and Cost (USD)/kWh

As previously mentioned, the power output (kW) found in the technical feasibility study is input into CREST. The LCOE (Cost/kWh) is also added in at this point from SAM [23,24]. This value can be found easily online by contacting the local electric company or by selecting the state the solar farm will be in with CREST. The software can autofill the value.

2.3.2. Inputs (2 and 3) Operation and Maintenance (O&M) and Capital Costs

The O&M Costs refers to the amount of money needed each year to maintain and run the solar farm [17]. We found rough estimates on the cost of operating a solar farm in Maryland based on the Nameplate Capacity of the solar panels installed and based our estimates on those values. Capital Costs refer to the initial investment needed to buy the property and build the solar farm. This value was based on the cost of the previously mentioned panels, the average installation cost for utility-scale solar for the state, and the property prices [17].

Input (4) Tax Incentives and Rebates: This input is in regard to tax breaks, incentives, and rebates the project can apply for and receive. There was a federal Investment Tax Credit that these solar farms would theoretically be able to apply for, and it would apply to 22% of the initial investment [25–27]. Maryland also offers a rebate for solar panels. The rebate amount is $20,000 plus an extra $80/kW, with the maximum amount any one project can receive set at $30,000 [25–27].

Input (5) Interest Rates and Debt Management: In this section, we include many different parameters, including the interest rate on an initial loan, inflation, lender's fees, tax status, etc., as shown in the following Table 3.

Table 3. Debt Management Section of CREST [17].

Permanent Financing	Units	Input Value
% Debt (% of hard costs) (mortgage-style amort.)	%	45%
Debt Term	*years*	18
Interest Rate on Term Debt	%	7.00%
Lender's Fee (% of total borrowing)	%	3.0%
Required Minimum Annual DSCR		1.20
Actual Minimum DSCR, occurs in →	*Year 18*	1.51
Minimum DSCR Check Cell (If "Fail", read note ==>)	*Pass/Fail*	Pass
Required Average DSCR		1.45
Actual Average DSCR		1.58
Average DSCR Check Cell (If "Fail", read note ==>)	*Pass/Fail*	Pass
% Equity (% hard costs) (soft costs also equity funded)	%	55%
Target After-Tax Equity IRR	%	12.00%
Weighted Average Cost of Capital (WACC)	%	8.47%
Other Closing Costs	$	$0

2.3.3. Output (1) LCOE ($/kwh)

The LCOE provides an effective tool to compare different energy resource technologies with different lifetimes, cost structures, and capacity factors from an economical perspective [17,28]. This acronym stands for Levelized Cost of Energy [24]. The LCOE Calculator uses a simple fixed-charge rate (FCR) method to calculate a project's levelized cost of energy (LCOE) using only the following inputs [27,28]:

- Capital cost: $ (TC);
- Fixed Annual Operating Cost: $ (CF);
- Variable Operating Cost: $/kWh (CV);
- Fixed charge rate: (CR);
- Annual electricity production, kWh (AEP).

The LCOE Calculator uses the following equation to calculate the LCOE:

$$\text{LCOE} = (\text{CR} \times \text{TC} + \text{CF})/\text{AEP} + \text{CV}$$

LCOE takes the lifespan cost of a solar farm divided by the power generated over the solar farm's lifespan. This value is given by the SAM program as a unit in cost/kWh. The values we have found fell between $68.8/MWh–$69.9/MWh. This is well above the Maryland average of $37/MWh [28]. Both the calculated value and the Maryland average, though, are better than the Maryland LCOEs for coal, which fall between $65/MWh–$159/MWh [28].

2.3.4. Output (2) Cumulative Cash Flows ($)

This shows the theoretical income each year, theoretical expenses, taxes on income, debt service, and net income. All these factors determine the profitability [17]. These values can be used to measure the viability and success of the solar farms

2.3.5. Output (3) Payback Period

Payback Period refers to the time needed to pay back the original investment plus interest to the lender. We also find the point at which the farm begins to make a net profit. These and other factors also help determine the viability of the farm, and in real-life scenarios, would be facts and figures presented to lenders to advocate for a loan [28]. Usually, the Payback period could be defined as the following:

$$\text{Payback period} = \text{Initial Investment}/(\text{Discount Rate} \times \text{Yearly Cash Flow})$$

3. Results

This section will introduce Annual Monthly Solar Irradiance, Energy Yield, AC System Output, and Cumulative Cash Flows via Expenses and Revenue over 25 years in three selected areas (Westover, Princes Ann, and Eden) of Maryland, USA. Three areas are located in Somerset County in the U.S. state of Maryland. As of the 2020 census, the population was 24,620, making it the second-least populous county in Maryland. To evaluate monthly output (GWh) for all three areas, the system configuration is determined using the SAM and PVWatts tools based on a 0.4 ground coverage ratio, a 1.2 DC to AC ratio, and a 96% inverter efficiency. Standard crystalline silicon panels with a nominal efficiency of 15% on one-axis tracking are assumed.

3.1. Location 1 (Westover)

The first selection location is located in Westover, MD, as depicted in Figure 7. In Figure 7, the outlined area marked with the red line represents the region selected for our simulation, chosen automatically based on the system. Various terms, such as solar radiation (electromagnetic), solar irradiance (for power), solar irradiation (for energy), and solar insolation, are employed to describe the amount of sunlight available at a specific location [23]. This paper focuses on solar irradiance (for power), and Figure 8 presents the Annual Monthly Average Solar Irradiance in kWh/m^2/day for Westover, MD. Figure 8 highlights that June exhibits the highest Solar Irradiance at 8.30, while December indicates the lowest value at 2.40, reflecting a 5.9 difference between them. According to NASA, the global daily average solar irradiance is approximately 5.0 kWh/m^2. Based on the global daily average solar irradiance, Consequently, the period from March to September represents a favorable time for solar PV power generation, totaling seven months with abundant resources in the area of Westover, MD. Also, the average solar irradiation is indicated to be 5.65 in kWh/m^2/day for a 2021 year.

Figure 7. Westover, MD. Property [26].

Figure 9 illustrates the Monthly Output from an AC Power System in the SAM [18]. The annual average output for a year is 16.75 GWh, with the period from March to September exceeding the average. July records the highest value of 24.80 GWh, while December reflects the lowest value of 8.04 GWh. The results illustrate an 8.05 kWh difference between the average and the highest output and a—8.71 GWh difference between the average and the lowest output, as shown in Figure 10. In Figure 11, the Accumulated Monthly output for Westover, MD, amounts to 200.98 GWh; in addition, the Energy Yield was evaluated to be 1583.12 kWh/kW from the SAM.

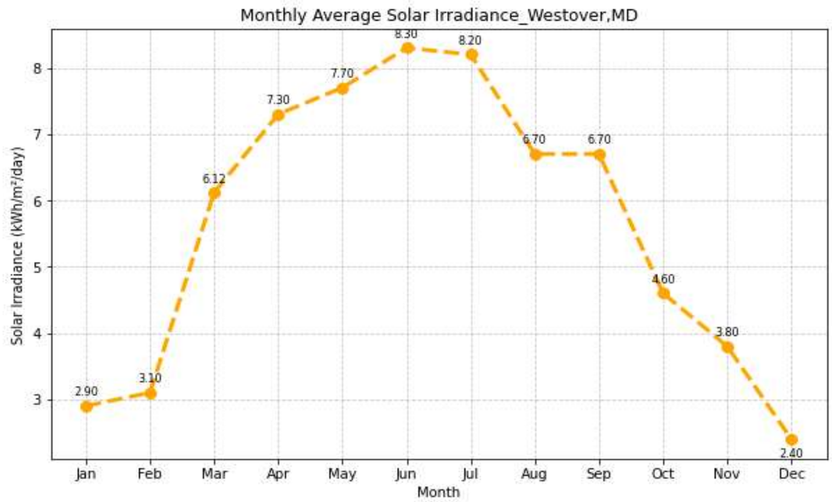
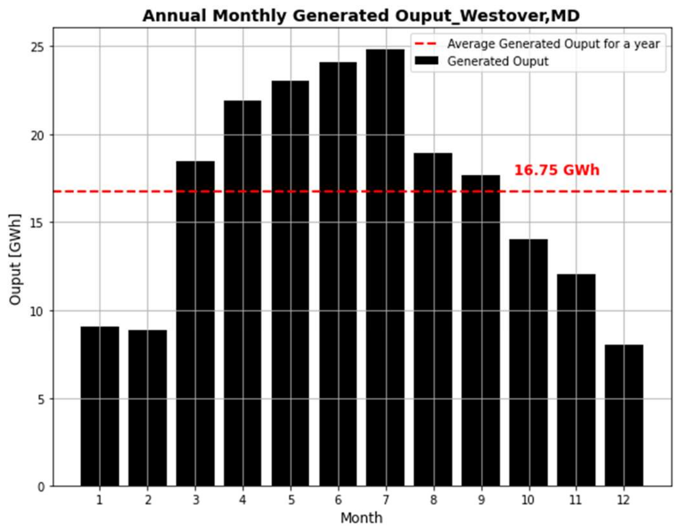


Figure 8. Monthly Average Solar Irradiance, Westover, MD.



Month	1	2	3	4	5	6	7	8	9	10	11	12
Ouput	9.09	8.90	18.50	21.90	23.00	24.10	24.80	18.90	17.70	14.02	12.03	8.04

Figure 9. Annual Monthly Output and Average Annual Output, Westover, MD.

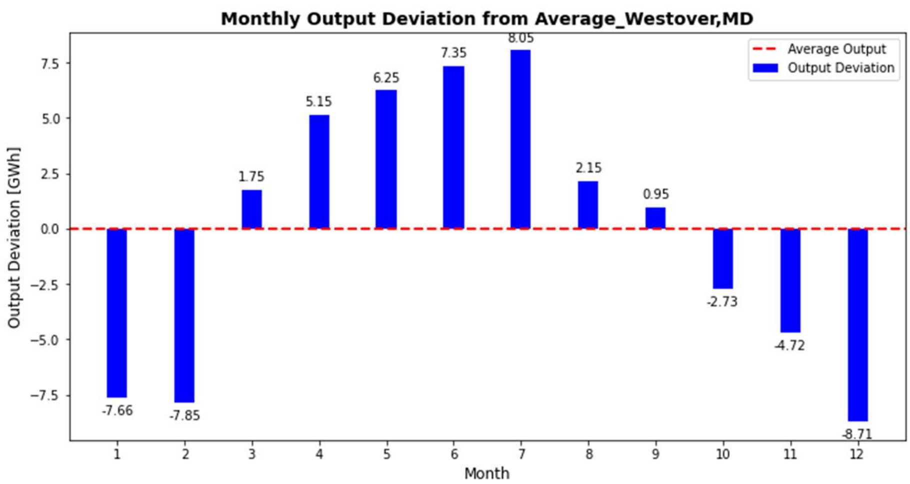


Figure 10. Annual Monthly Power Deviation from the Average, Westover, MD.

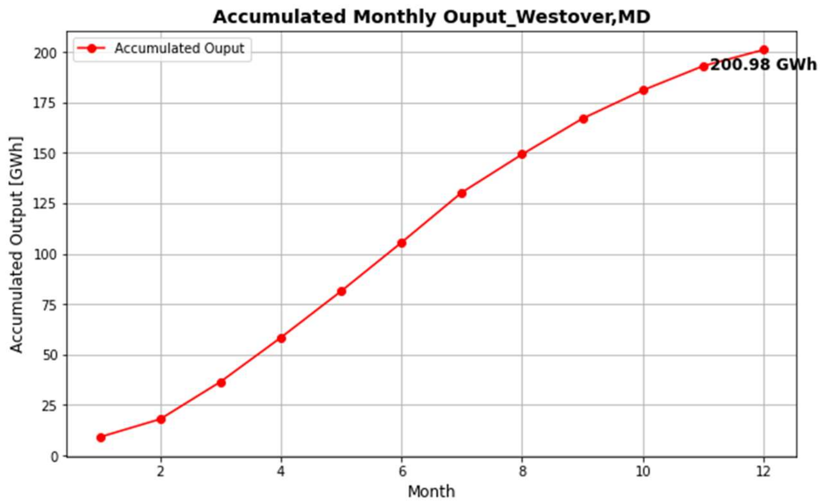


Figure 11. Accumulated Monthly output, Westover, MD.

Through analysis with CREST, the final cumulative cash flow, depicted in Figure 12, reaches $95,993,747 after the 25-year lifespan of the panels. Notably, profitability is achieved in the third year. The levelized cost of energy (LCOE) is calculated to be 5.99 cents/kWh.

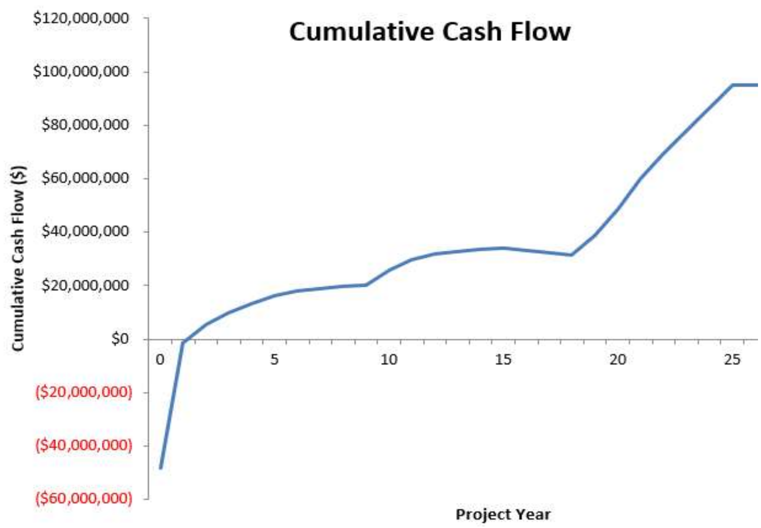


Figure 12. Cumulative Cash Flows over 25 years for Westover, MD [17].

3.2. Location 2 (Princess Anne)

The second site, denoted as Princess Anne, MD, is situated in the southeast region of Maryland and represents the largest among the selected three farms [3,10], as depicted in Figure 13. In the Figure 13, the outlined area marked with the yellow line represents the region selected for our simulation, chosen automatically based on the system.

In this context of Figure 14, July registers the highest value at 8.36, while December marks the lowest value at 2.45, indicating a 5.91 difference between the two. The period from March to September emerges as an opportune timeframe for solar PV power generation, encompassing seven months abundant with resources in Princess Anne, MD, area.

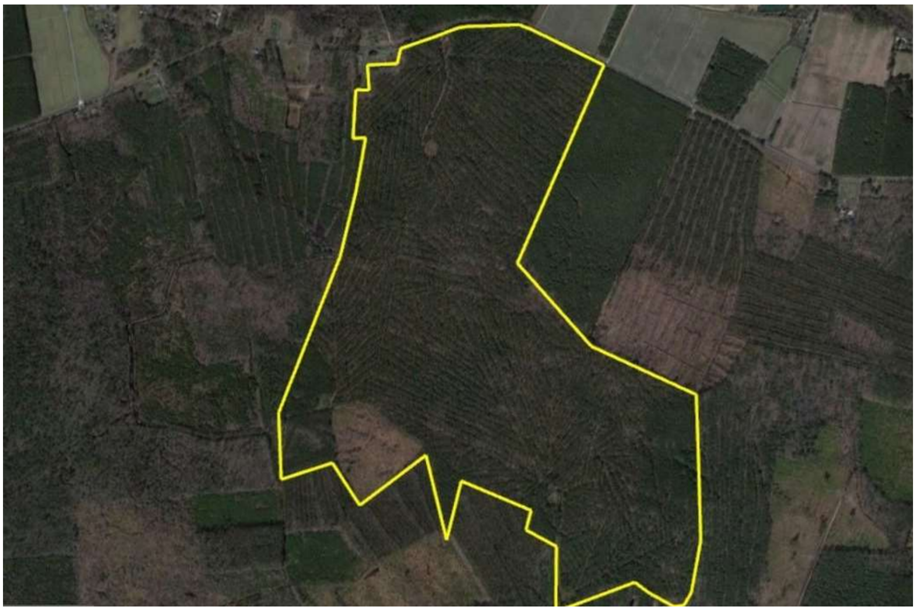


Figure 13. Princess Anne, MD, Property [26].

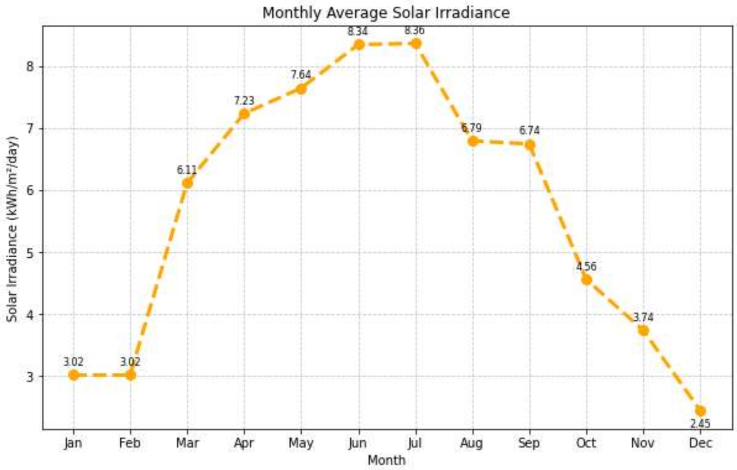
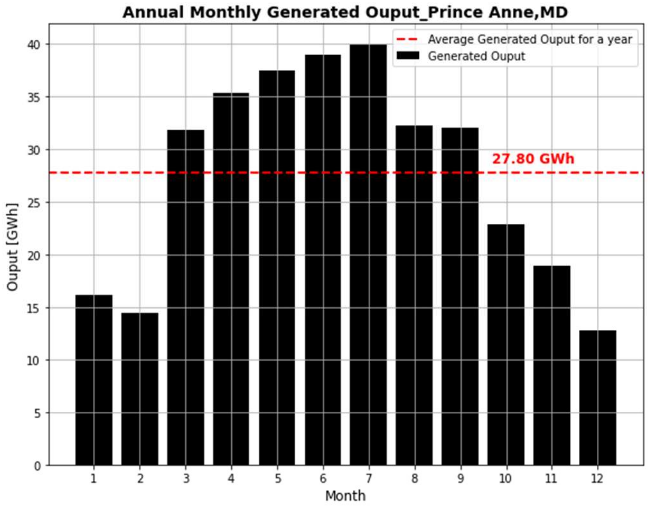


Figure 14. Monthly Average Solar Irradiance in kWh/m^2/day for Princess Anne, MD.

Examining the Annual Monthly Output of an AC Power System in Figure 15, the average output is calculated as 27.80 GWh. The period from March to September surpasses the average, aligning with the solar irradiance results in the same timeframe. July records the highest value of 39.92 GWh, while December reflects the lowest value of 12.85 GWh. Figure 16 illustrates a 12.12 GWh difference between the average and the highest value and a −14.95 GWh difference between the average and the lowest value. The Accumulated Monthly Power for Princess Anne, MD, amounts to 333.95 GWh, as depicted in Figure 17. Also, the Energy Yield was evaluated to be 1565.2 kWh/kW from the SAM.



Month	1	2	3	4	5	6	7	8	9	10	11	12
Ouput	16.25	14.55	31.84	35.39	37.48	38.98	39.92	32.32	32.03	22.96	19.01	12.85

Figure 15. Monthly Generated Output, Princess Anne, MD.

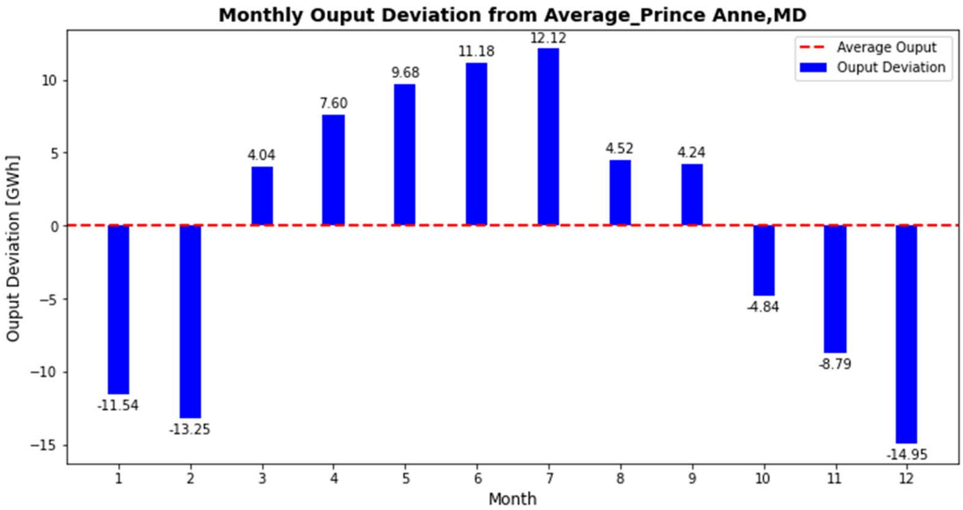


Figure 16. Monthly Energy Deviation from average for Princess Anne, MD.

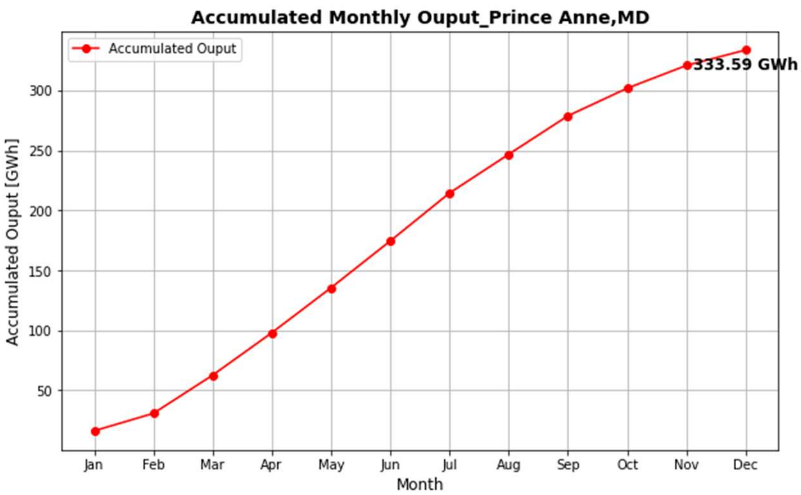


Figure 17. Accumulated Monthly Output, Princess Anne, MD.

According to CREST, the final cumulative cash flow is detailed in Figure 18, indicating a total of $183,393,304 after the 25-year lifespan of the panels. Notably, profitability is attained in the third year. The Levelized Cost of Energy (LCOE) is calculated at 6.06 cents/kWh.

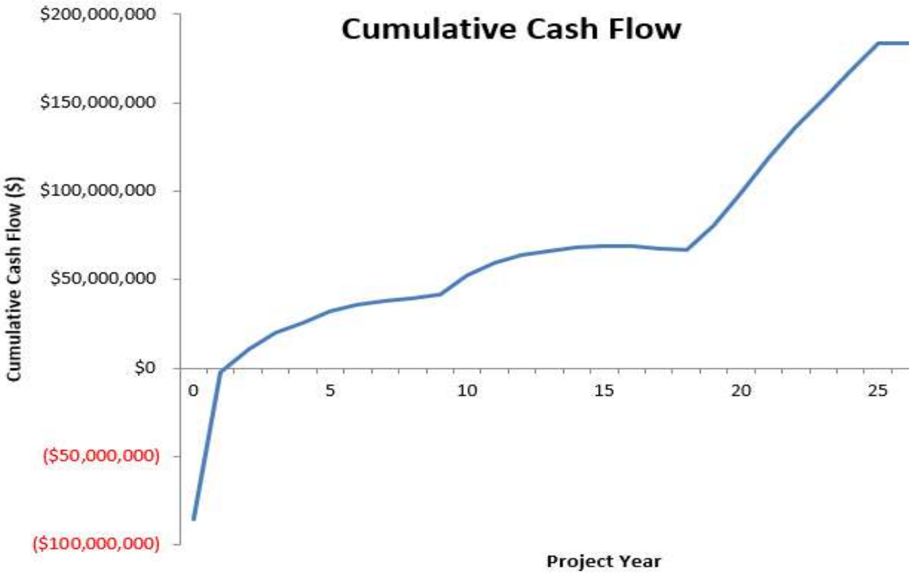


Figure 18. Cumulative Cash Flows over 25 years for Princess Anne, MD [17].

3.3. Location 3 (Eden)

The third designated site, identified as Eden, MD, is depicted in Figure 19. In Figure 19, the outlined area marked with the red line represents the region selected for our simulation, chosen automatically based on the system. Figure 20 shows the Monthly Average Solar Irradiance in kWh/m^2/day for Eden, MD. In this context, July records the highest value at 8.50 kWh/m^2/day, while December represents the lowest value at 2.44 kWh/m^2/day, representing a 6.06 difference between the two. Relative to the average solar irradiance across the USA, approximately 5.0 kWh/m^2, the period from March to September emerges as an optimal timeframe for solar PV power generation, spanning seven months rich in resources in the Eden, MD, area.

Figure 19. Eden, MD, Property [26].

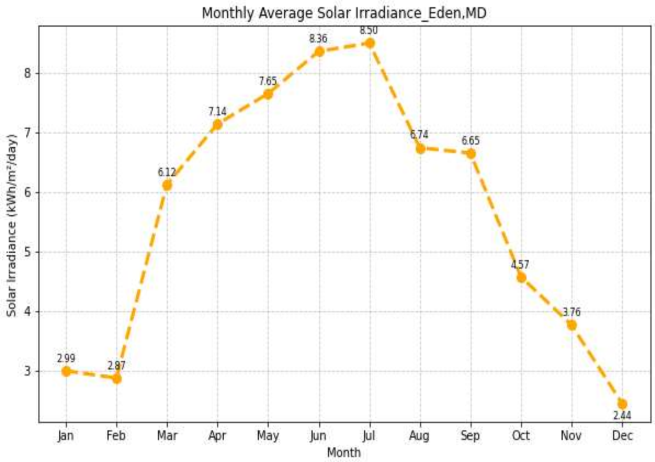
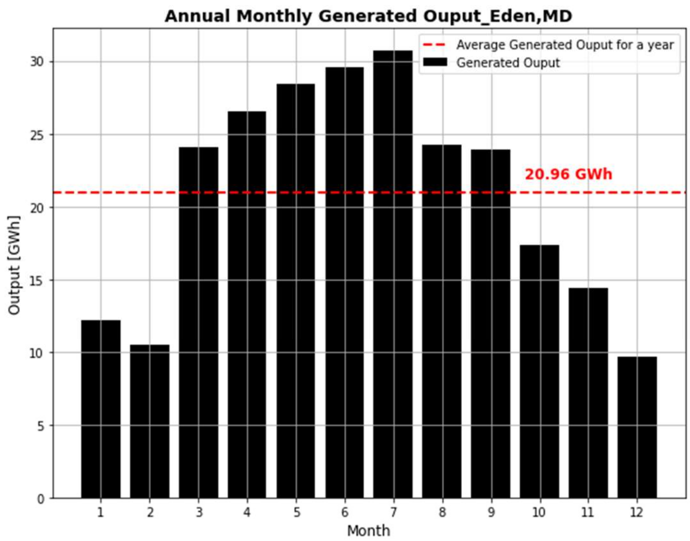


Figure 20. Monthly Average Solar Irradiance, Eden, MD.

Analyzing the 2021 Monthly Output as an AC Power System in Figure 21, the average output was calculated as 21.86 GWh. The period from March to September surpasses the average, aligning with the solar irradiance results during the same timeframe. July records the highest value of 31.96 GWh, while December reflects the lowest value of 10.12 GWh. Figure 22 illustrates a 9.73 GWh difference between the average and the highest value and a −11.30 kWh difference between the average and the lowest value. The Accumulated Monthly Energy for Eden, MD, amounts to 251.58 GWh, as depicted in Figure 23. Energy Yield was indicated to be 1558.48 kWh/kW from the SAM. According to CREST, the final cumulative cash flow, after the 25-year life span of the panels, reached $127,379,639, as presented in Figure 24. The farm achieved profitability in the third year. The Levelized Cost of Energy (LCOE) stands at 6.09 cents/kWh—the highest among the three locations [16].



Month	1	2	3	4	5	6	7	8	9	10	11	12
Ouput	12.20	10.47	24.12	26.51	28.38	29.53	30.69	24.27	23.89	17.39	14.47	9.66

Figure 21. Monthly Generated Output, Eden, MD.

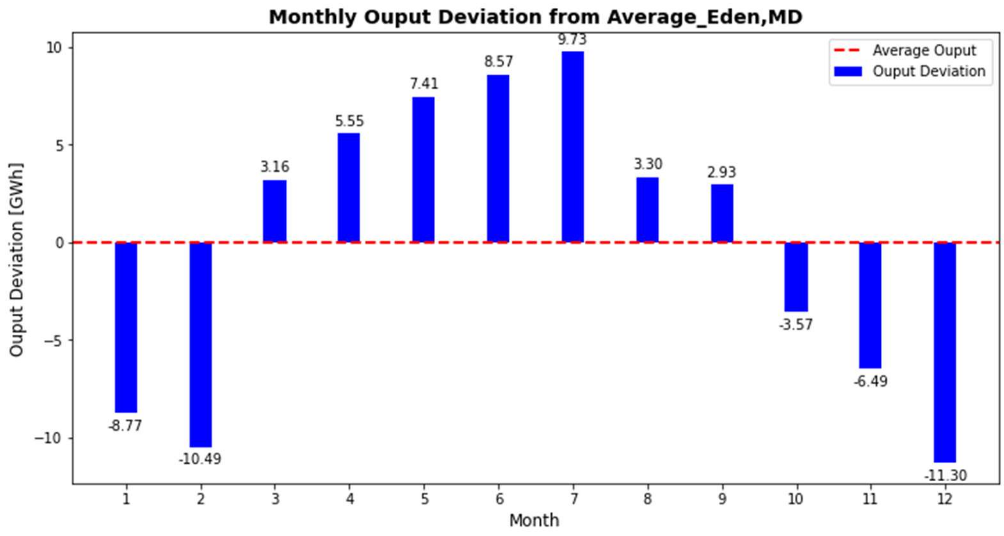


Figure 22. Monthly Generated Output Deviation, Eden, MD.

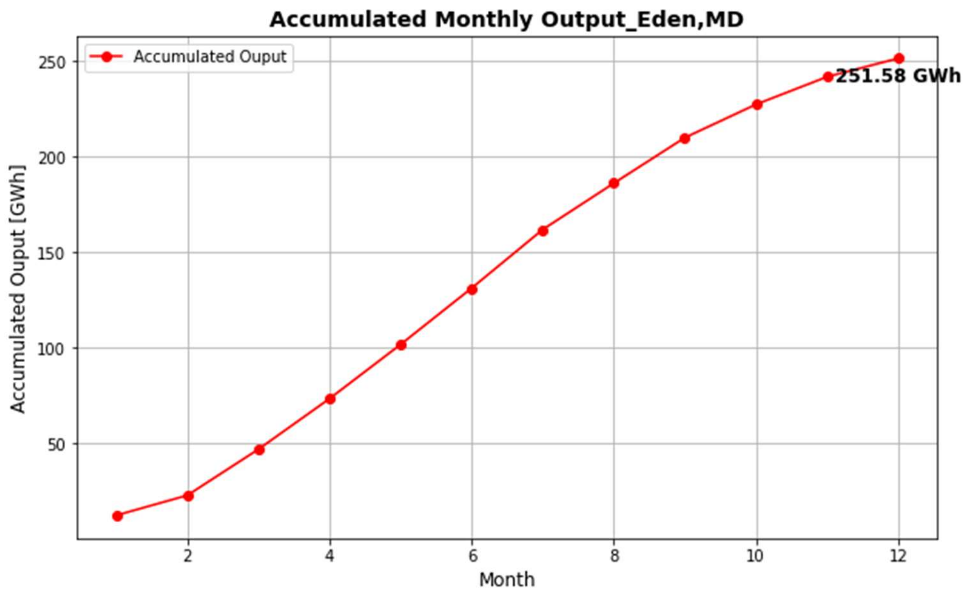


Figure 23. Accumulated Monthly Output, Eden, MD.

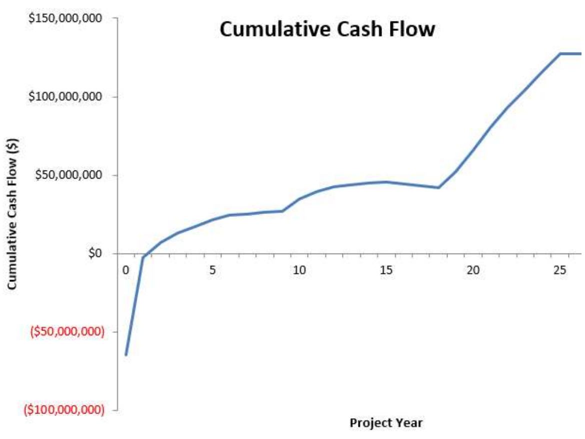


Figure 24. Cumulative Cash Flows over 25 years for Eden, MD [17].

4. Summary and Discussion

Tables 4 and 5. Are the summary of Technical and Economic feasibility study for the selected three areas. All three locations had similar solar irradiation layers due to having almost identical latitudes and weather conditions. Westover had slightly higher readings but only by approximately 0.1–0.2 kWh/m^2/day [3,10]. Due to high solar irradiation, the Westover area has the highest energy yield at 1583.13 kWh/kW, while Princess Anne and Eden had values of 1565.2 and 1558.48 kWh/kW, respectively [3].

Table 4. Summary of Technical feasibility study for the selected three areas.

Properties	Average Annual Solar Irradiation (kWh/m^2/Day)	Energy Yield (kWh/kW)	System Output (GWh)
Westover, MD	5.81	1583.13	200.98
Princess Anne, MD	5.67	1565.20	333.59
Eden, MD	5.64	1558.48	251.58

Table 5. Summary of Economic feasibility study for the selected three areas.

Properties	Cumulative Cash Flow over 25 Years ($)	LCOE (Cents/kwh)
Westover, MD	$95,993,747	5.99
Princess Anne, MD	$183,383,304	6.06
Eden, MD	$127,379,639	6.09

Princess Anne had a significantly higher accumulated annual monthly output than the other two areas at 333.59 GWh annually, as opposed to Westover and Eden at 200.98 GWh and 251.58 GWh. This is expected, though, considering the Princess Anne location accommodates the largest number of solar panels and Westover the least [3]. Likely due to its higher solar irradiation values and higher Energy Yield, when it comes to LCOE, Westover is the cheapest option at 5.99 cents/kWh, compared to Princess Anne and Eden at 6.06 and 6.09 cents/kWh. This LCOE is slightly higher than average for the state in regard to utility-scale solar. However, SAM does not account for federal investment tax credits or state performance-based incentives. The payback period for all of the properties is approximately 2 years.

At this point, the farms have made a net profit higher than the original investment. Although, based on the loan terms in CREST, debt repayment will continue for 18 years. Cumulative cash flow is also shown below in the table. Princess Anne had the highest cash flow at $183 million over 25 years, which on average is over $7.3 million a year when averaged. Eden made $127 million over 25 years, or just over $5 million a year. Westover had the lowest cash flow at $96 million over 25 years, which averaged $3.83 million a year [2,3]

5. Conclusions

This paper investigates the feasibility of implementing solar photovoltaic (PV) power installations in the state of Maryland, USA. The escalating concern about climate change and the depletion of conventional energy sources has driven a shift towards renewable energy, with solar PV emerging as a frontrunner. This feasibility study employs advanced tools like the System Advisor Model (SAM) and The Cost of Renewable Energy Spreadsheet Tool (CREST) to comprehensively assess technical, economic, and environmental aspects.

The study follows a three-stage approach:

1. **Location Selection:** Three potential areas—Westover, Eden, and Princess Anne—are identified based on terrain, solar irradiance, cost, and proximity to load. These criteria help optimize site selection;

2. **Technical Feasibility:** Detailed analyses using SAM and PVWatts determine yearly and monthly outputs, and energy yields. Multiple parameters, including Solar PV panel and inverter specifications, are considered to accurately estimate energy generation;
3. **Economic Feasibility:** CREST is employed to evaluate project economics, considering factors such as power output, costs, tax incentives, rebates, interest rates, and debt management. Cumulative cash flows, levelized cost of energy (LCOE), and payback period are key metrics.

Results from the three locations are compared, highlighting differences in energy yields, cash flows, and LCOE. Westover, with its high solar irradiance, exhibits the lowest LCOE and the highest cumulative cash flow. Princess Anne has the largest farm and shows significant profitability after two years. Eden, though yielding the least energy, also becomes profitable after two years. The paper concludes by emphasizing the importance of advanced simulation tools in shaping sustainable energy trajectories and decision-making processes for regions transitioning to renewables, offering insights for both local and broader contexts.

In concluding this study, we recognize the need for further in-depth exploration in two key areas for future research. Firstly, while applying the SAM-CREST model to solar PV power plants, we aim to conduct specific case studies and comparative analyses with actual operational data in future studies, thereby verifying the model's practical application and accuracy. Secondly, we plan to rigorously analyze the economic feasibility, operational costs, and environmental impacts of tracking systems in solar PV installations. This future research will not only strengthen the reliability of the SAM-CREST model but also provide a deeper understanding of the overall sustainability and utility of solar PV technology.

Author Contributions: Conceptualization, Y.K.; methodology, Y.K. and A.S.; software, A.S.; validation, A.S. and Y.K.; formal analysis, Y.K.; investigation, A.S.; resources, A.S.; data curation, Skaggs, A; writing—original draft preparation, A.S.; writing—review and editing, Y.K.; visualization, Y.K.; supervision, Y.K.; project administration, Y.K. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Category and Descriptions for PVWATTS.

Category	Input	Description
Age Losses	%	Losses due to degradation over time because of weathering
Albedo		Amount of sunlight reflected by the ground
Array Type		Fixed (open mount), Fixed (roof mount), 1-Axis Tracking, 1-Axis Backtracking, 2-Axis Tracking
Availability Losses	%	Losses due to scheduled maintenance
Azimuth	Degrees	Degrees away from true north (clockwise)
Bifacial	Yes/No	
Connections Losses	%	Resistive losses in the electrical connectors of the panels

Table A1. *Cont.*

Category	Input	Description
DC System Size	kW	
DC to AC Size Ratio		"ratio of the array's DC rated size to the inverter's AC rated size"
Ground Coverage Ratio		"ratio of module surface area to the area of the ground or roof occupied by the array"
Inverter Efficiency	%	Dc-to-AC converter efficiency
Light-Induced Degradation Losses	%	Losses due to light degradation of the PV cells
Location	Address or Coordinates	
Mismatch Losses	%	Electrical losses due to manufacturing differences between panels
Module Type		Standard, Premium, or Thin Film
Monthly Irradiance Losses	%	A place to account for losses that are not applicable all year
Nameplate Rating Losses	%	Losses due to the nameplate rating being inaccurate
Shading Losses	%	Losses due to lost incident solar radiation due to shadows from nearby objects or other panels
Snow Losses	%	Losses due to snow covering the panels
Soiling Losses	%	Losses due to soil or other debris on the panel
Tilt	Degrees	Degrees away from horizontal

Table A2. Category and Descriptions for the SAM.

Category	Input	Description
Location	Address or Coordinates	
Age Losses	0.7%	Losses due to degradation over time because of weathering
Albedo		Amount of sunlight reflected by the ground
Analysis Period	years	Period analyzed
Annual Cost during Construction	% of capital cost	
Array Type		
Availability Losses	%	Losses due to scheduled maintenance
Azimuth	Degrees	Degrees away from true north (clockwise)
Bifacial	Yes/No	
Capital Cost	$	Original investment
Connections Losses	%	Resistive losses in the electrical connectors of the panels
DC System Size	kW	
DC to AC Size Ratio		"ratio of the array's DC rated size to the inverter's AC rated size"
Depreciation Schedule	% of capital cost	
Effective Tax Rate	%/year	
Fixed Operating Cost	$	Operating and maintenance costs
Grid Curtailment	MW	Debt interest rate limits on the system's power
Grid Interconnection Limits	kWac	The system cannot export power above this value

Table A2. *Cont.*

Category	Input	Description
Ground Coverage Ratio		"ratio of module surface area to the area of the ground or roof occupied by the array"
Inflation Rate	%/year	
Internal Rate of Return	%/year	
Inverter Efficiency	%	Dc-to-AC converter efficiency
Light-Induced Degradation Losses	%	Losses due to light degradation of the PV cells
Mismatch Losses	%	Electrical losses due to manufacturing differences between panels
Module Type		Standard, Premium, or Thin Film
Monthly Irradiance Losses	%	A place to account for losses that are not applicable all year
Nameplate Rating Losses	%	Losses due to the nameplate rating being inaccurate
Nominal Construction Interest Rate	%/year	
Nominal debt interest rate	%/year	
Project Term Debt	% of capital cost	
Shading Losses	%	Losses due to lost incident solar radiation due to shadows from nearby objects or other panels
Snow Losses	%	Losses due to snow covering the panels
Soiling Losses	%	Losses due to soil or other debris on the panel
Tilt	Degrees	Degrees away from horizontal
Variable Operating Costs	$/kW	
Wiring Losses	%	Resistive losses in the wiring of the panels

Table A3. Category and Descriptions for the CREST.

Category	Input	Description
Technology	Photovoltaic	Type of solar technology being used
Generator Nameplate Capacity	Varies on Location	Assumed system capacity
Net Capacity Factor	State Average	The options here are to enter a custom factor or to select the State Average
State	KY	If the State Average is chosen, enter the state here
Annual Production Degradation	0.50%	The annual percentage of the system has degraded. The value used was based on typical degradation for the panels used
Project Useful Life	25	How long the panels are expected to last before needing replacement
Total Installed Cost	Varies on Location	Total costs for standard operation, maintenance, etc., in $(USD)/Watt DC. This was based on averages for solar farms of similar size in areas with similar income
Fixed O & M Expense, Yr 1	$6.50/kW-yr dc	Total expected fixed costs
O & M Cost Inflation, Initial Period	1.60%	Inflation rate 1 will last over a set initial period
Initial Period Ends Last Day Of:	10	The time period over which inflation rate 1 lasts
O & M Cost Inflation, thereafter	1.60%	Inflation Rate after the initial period ends
% Debt	45%	The theoretical amount of funds borrowed
Debt Term	18	Number of years for debt repayment

Table A3. *Cont.*

Category	Input	Description
Interest Rate on Term Debt	7%	Interest rate set by the lender
Lender's Fee	3%	One-time fee collected by the lender
DSCR	1.2–1.45%	Debt Service Coverage Ratio is yearly cash flow/(annual principal + interest)
Target After-Tax Equity IRR	12%	Minimum rate of return
Other Closing Costs	0%	Any additional costs
Is the owner a taxable entity?	Yes	
Federal Income Tax Rate	35%	
Federal Tax Benefits used as generated or carried forward?	Generated	Determines whether deprecation is monetized as it occurs or after the project has a sufficient tax liability
State Income Tax Rate	0%	
State Tax Benefits used as generated or carried forward?	Generated	Determines whether deprecation is monetized as it occurs or after the project has a sufficient tax liability
Payment Duration for Cost-Based Tariff		FIT Contract length—determined by policymakers
% Of Year 1 Tariff Escalated		The portion of the tariff that can be escalated
Cost-Based Tariff Escalation Rate		Used to account for levelized nominal tariff rate
Federal Incentives	Cost-Based	
Investment Tax Credit (ITC) or Cash Grant?	ITC	
ITC Amount	22%	
ITC Utilization Factor	100%	How much of the project expenses the ITC can be applied to
Additional Federal Grants	0	
Federal Grants Treated as Taxable Income?	No	
State Rebates/Grants	No	
$ Cap on State Rebates/Grants	$500,000	The maximum amount of state grants or rebates a project can legally accept
State Grants Treated as Taxable Income?	No	
1st Equipment Replacement	10	The year that equipment will need maintenance/replacement
1st Replacement Cost ($ in year replaced)	$0.24	
2nd Equipment Replacement	20	The year that equipment will need a second maintenance/replacement
2nd Replacement Cost ($ in year replaced)	$0.24	
Number of months of Debt Service	6	Lenders often require a debt service amount set aside equal to x amount of months' repayment
Number of months of O&M Expense	6	How many months of O&M should be set aside in a reserve account
Interest on All Reserves	2%	

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