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Small Scale PV Integration in Bangladesh: Opportunities, Challenges, and Recommendation

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***Abstract*—In the early 2000s, the Bangladesh government introduced nano and micro-scale photovoltaic (PV) systems in remote areas. As the power sector continues to grow, these nano-scale PV systems are becoming economically impractical. Additionally, the existing PV market policies are not sufficiently attractive to the mass population for installing small-scale PV systems known as SHS through private initiatives. This study aims to replicate the current SHS policies and pricing, assess the obstacles, and evaluate the economic viability of the current SHS system. Load profiles of three consumers are constructed and utilized to evaluate the economic feasibility of the existing system. Furthermore, various renewable-friendly policies, incentives, and net metering are applied to explore the economic viability of a modified system. The REopt tool is used to verify the economic feasibility, employing three hypothetical scenarios to assess the effectiveness of these policies and strategies in making SHS more appealing to the general population. Residential and small business load profiles are simulated using REopt. The findings of this research indicate that the implementation of net metering, combined with appropriate financial policies, can enhance the attractiveness of SHS to the mass population. These results provide valuable insights for policymakers and stakeholders to shape future initiatives and promote the widespread adoption of small-scale PV systems in Bangladesh.**

***Index Terms*—Solar Home Systems, Renewable Energy Systems, Green House Gas Reduction, Energy Policies.**

I. Introduction

Bangladesh, a developing nation in South Asia, is currently grappling with a significant energy shortage. The country is unable to meet its electricity demand at a satisfactory level. While approximately 88% of the population has access to electricity, a substantial portion of the grid-connected individuals, around 79%, endure frequent power cuts due to load-shedding. Additionally, about 60% of the population faces issues related to low-voltage supply, further exacerbating the energy challenges in the country [1]–[3]. Renewable energy technologies, especially solar home systems (SHS), offer viable solutions for equitable development in remote areas. In March 2022, Bangladesh had a total installed capacity of 579 MW of renewable energy. This includes on-grid and off-grid installations. The on-grid generation consisted of 225.51 MW from hydro, 338.81 MW from solar, and the remaining capacity from wind sources. The off-grid generation mainly relied on solar home systems (SHS), with additional contributions from biogas-to-electricity (0.63 MW), biomass-to-electricity (0.40 MW), and wind (2 MW). The majority of the SHS capacity, totaling 288.81 MW, was developed by the Infrastructure Development Company Limited (IDCOL) with 231.85 MW, followed by the Ministry of Disaster Management and Relief with 57.14 MW. The government was also involved in SHS capacity development, with approximately 63.55 MW through initiatives such as solar street lighting and rooftop solar systems in urban areas. The Bangladesh Rural Electrification Board and GIZ, a German development agency, contributed to the remaining SHS capacity [4]–[6]. Most "SHS" home solar systems, while users expressed satisfaction with the system, they also noted shortcomings, such as a lack of technical knowledge and poor customer service. The price of SHS was seen as a major obstacle as users struggled to make upfront payments and pay monthly installments. About 8% of the solar panels did not perform optimally due to shading and aging over time. Users have reported that the battery was draining, the battery was overheating, and fluorescent lights were dimmed. Improper disposal of used components poses a risk to the environment [7], [8]. However, there is a lack of research to determine the optimal niche for SHS in Bangladesh. Obstacles such as limited technical knowledge, lack of awareness, financial constraints, and insufficient information hinder the sustainable development of SHS in rural areas.

Earlier researchers tried to investigate the feasibility analysis and impact of SHS in specific areas in South Asian countries like Bangladesh, India, Pakistan, etc. According to the study conducted by the authors, the availability of solar photovoltaic (PV) systems in the local market and their environmental benefits were identified as the primary factors driving their adoption at the household level. On the other hand, the cost of solar PV systems and the lack of adequate government financing options were recognized as the main obstacles hindering their adoption [9], [10]. The impact of Solar Home Systems (SHS) on energy consumption and expenditure in three districts of Bangladesh was examined by some research. Through their analysis, which involved a reflexive comparison, they observed a significant decrease in kerosene consumption (ranging from 50% to 60%, depending on the type of SHS) and negligible use of rechargeable batteries following the implementation of SHS [11]. Furthermore, a study in 2013 to evaluate the impact of Solar Home Systems (SHS) on various outcomes was conducted. Their sample consisted of 4,000 households, divided between villages with SHS access and those without. The authors employed propensity score estimation and attributed several effects to the availability of SHS, with one of the most compelling findings being a significant reduction of two liters (approximately 67%) in kerosene consumption [12]. In the Gazipur district, a feasibility study on Solar Home Systems (SHS) with capacities of 25, 30, and 40 Wp was studied. Similarly, the feasibility of SHS in the Sirajganj and Jessore districts was observed, focusing on capacities. However, no previous research has specifically examined the feasibility of the current SHS capacities considering their socio-environmental impacts and barriers, which have significant implications for the development of policy guidelines [13]–[16].

The key problems towards installing Solar Home Systems (SHS) through private initiatives can be summarized as follows: high capital cost, unreliable and low-efficiency systems, high operation and maintenance cost for off-grid systems, short battery life cycle, lengthy payback periods that render some systems unprofitable, lack of environmental concerns, and a lack of government policies, incentives, and good financial models. Another significant problem is the lack of knowledge and skills in implementing SHS. People are not inclined to adopt SHS due to a lack of understanding of environmental hazards. However, if SHS becomes financially profitable with shorter payback periods, lower capital costs, and installment payment options, it can gain popularity and trust among energy consumers.

The main objective of the research work is to address the obstacles mentioned earlier and assess the economic viability of the current Solar Home Systems (SHS) policies and pricing. The researchers constructed yearly load profiles for three consumers and used them to evaluate the economic feasibility of the existing system. They also explored the impact of implementing renewable-friendly policies, incentives, and net metering on the modified system's economic viability. To assess the economic feasibility, they utilized the REopt tool.

II. Analysis Conditions and Simulink Model

In this section, the load information from the house is used to create a load profile. Here, all load data is collected by monitoring user activity for a few days. Also included are the number of loads, their power ratings, and the typical summer runtime. A 24-hour load profile of a house over the course of a year must be used in the REopt lite web tool. The custom load profile needs 8760 hours of load data for an entire year that including all of the variations in the load profile according to the various seasons.

A. Load Profile

We generated this load profile by following the method outlined in a recent paper [17], which demonstrated how to create realistic load profiles using Excel and MATLAB Simulink. Here's the list of the load in the house along with their power consumption, as presented in TABLE II:

TABLE I. List of household loads

Name	Quantity	Power Rating (Watt)	Average Summer Runtime (hr)	Average Winter Runtime (hr)
LED	6	18	5	5
Energy Saving Bulb	3	26	6	6
Ceiling Fan	4	70 to 75	10 to 15	0
Laptop	5	50 to 100	3 to 5	3 to 5
Smartphone	6	10 to 30	2	2
Desktop	1	130	3	3
Trimmer	1	10	1	1
Router	1	7	24	24
TV	1	100	5	5
Telephone	1	10	24	24
Total	**29**			

In Fig. 1, we can see the Simulink representation of the house. We've included an AC voltage source that provides power to the home. It's important to note that this voltage source isn't constant; its value fluctuates between approximately 210 to 230 V. This variability reflects the real-world conditions of our power system. Additionally, we've incorporated some standard measurement blocks that function as electric meters. These blocks measure the voltage, current, and power consumption of the house. The main objective of simulating this house in

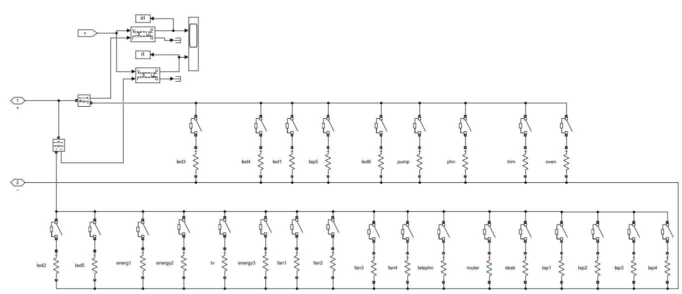

Fig. 1. Different loads of the house

Simulink is to generate two distinct real-time load profiles for both the summer and winter seasons.

B. 24-Hour Load Profile Simulation Results

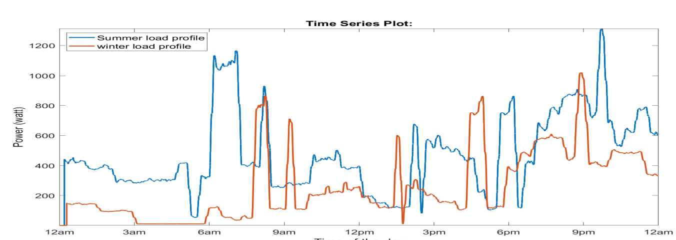

Fig. 2. Summer and winter season load profile of the house

C. Yearly Load Profile for 24 H

In this section, we illustrate the yearly load profile of the house, as displayed in Table II.

TABLE II. Yearly Load Profile

Hour	Electrical Load (kW)	Hour	Electrical Load (kW)
1	0.148	.....	.....
2	0.066	.....	.....
3	0.02	8750	0.307
.....	**.....**	8758	0.505
.....	.....	8759	0.483
.....	.....	8760	0.301

In Bangladesh, the summer season typically spans from early March to late October, lasting for over 8 months. In contrast, the winter season begins around mid-November and concludes in mid to late February, spanning approximately 3 to 3.5 months. Consequently, we had to align our hourly load profile data with these distinct summer and winter seasons. However, this straightforward approach encounters challenges due to the high variability and unpredictability of the load profile over time.
Observing someone's load profile for a few days. Then based on the observation take an average usage case and make an average load profile. Then converting it for the whole year keeping different seasons in mind and modifying it accordingly. For this approach - different season data, and random sequencing can be used together. This approach can yield a result that will be around 60 to 70% accurate. We have followed this approach and it is the practical one to work with. Although the accuracy of the load profile is around 70% it eventually represents the power usage scenario of a middle-class house in Bangladesh. The yearly load profile of the house is shown in Fig. 3.

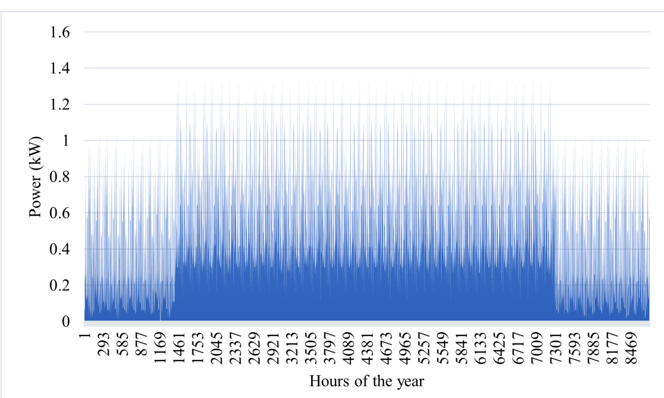

Fig. 3. Yearly load profile

Ultimately, we present a comparison of the weekly load profiles for summer and winter in Fig. 4. Using this load profile and similar ones, our objective is to enhance the renewable energy landscape in Bangladesh while identifying the impediments that may hinder progress.

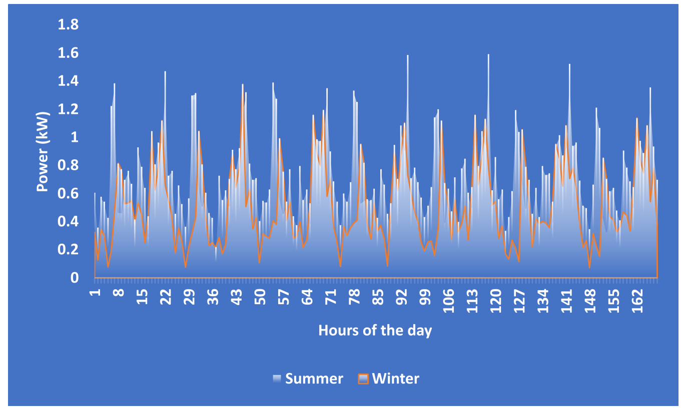

Fig. 4. Summer vs winter weekly load profile

D. Other Load Profile

In this research study, we have considered a residential and a small business load profile. We have provided an extensive explanation of the process involved in creating a single load profile. Subsequently, we will present the load profiles for both the compact residential home and the small business.

1) Small Business/Office: We have analyzed a small business with a peak load of approximately 20 kW. In our evaluation of this consumer, we have factored in one non-operational day each week, specifically on Fridays. The annual load profile is depicted in Fig. 5 below.

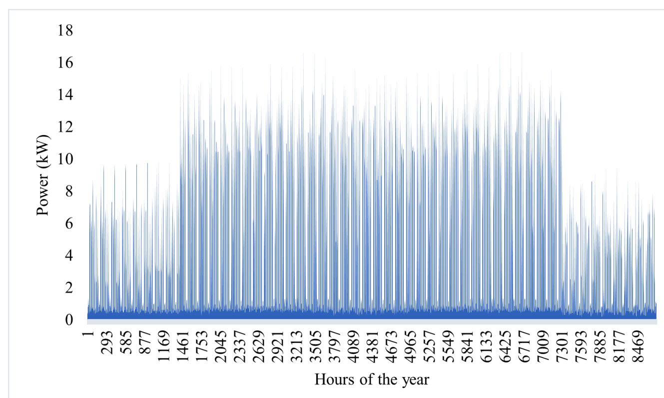

Fig. 5. Annual load profile for a small business

The weekly power consumption pattern for this business owner during both the summer and winter seasons is illustrated in Fig 6. It's evident that power consumption is significantly higher during working hours throughout the week and drops to a minimum level towards the end of the week. Interestingly, even during nighttime hours when work is not in progress, power consumption remains consistently low, typically from the 22nd hour to the 29th hour of the weekly cycle.

We will utilize these three load profiles as the basis for conducting our optimization in REopt Lite.

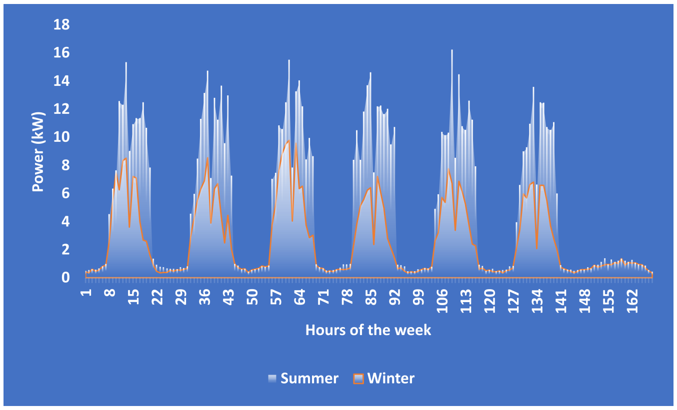

Fig. 6. Weekly load profile of the small business in summer and winter

III. Optimizing Renewable Resources Using the REopt Lite Web Tool

REopt, derived from 'renewable energy optimization,' is a versatile tool applicable in both online and offline environments. It facilitates the evaluation of diverse aspects of renewable energy projects, including economic feasibility, resilience analysis, environmental impact assessment, and more. These assessments are based on a variety of factors and technologies, encompassing PV, wind, energy storage, CHP, and diesel engines [18]. The tool can provide recommendations for technologies, system size, and operational strategies that can enhance the project's long-term viability. REopt Lite additionally calculates the duration for which on-site generation and storage can support critical loads during grid interruptions, offering users the flexibility to prioritize either energy resilience or clean energy objectives. Its primary utility lies in guiding project development choices and facilitating research related to the factors influencing project feasibility, which in turn supports market development and policy analysis efforts.

A. Optimization Scenarios

In this section, we illustrate four scenarios that align with the goals of this research. These scenarios have been simulated for all three load profiles.

1) Grid-Connected PV System without Net Metering - 15 years of operational lifespan
2) Grid-Connected PV System with Net Metering - 15 years of operational lifespan
3) Grid-Connected PV System with Net Metering - 25 years of operational lifespan for the generator.
4) Grid-Connected PV System with Net Metering and Government Incentives - 25 years of operational lifespan for the generator.

B. Residential Consumer

In this subsection, we have provided a comprehensive examination of the residential load profile. Now, let's delve into the input parameters and the results obtained from the simulation.

C. Scenario 1

Scenario 1 corresponds to the existing situation of Solar Home Systems (SHS) in Bangladesh. The input parameters for Scenario 1 can be found in the attached PDF file, which was exported from REopt (please refer to the provided reference). This PDF contains a comprehensive list of all input parameters, including those that were manually entered and those that were automatically set as defaults. In the referenced report, critical input data such as location details, site-specific technology information, tariff rates, load profiles, system life cycle duration, greenhouse gas emissions data, and the capital cost per kilowatt of the system have been documented and utilized for the simulation. REopt has leveraged these input values to generate an optimization report, the details of which can be found in the report itself.

Table III illustrates the primary findings and outcomes of the simulation report generated by REopt.

TABLE III. Result of scenario 1 of residential consumer

Parameters	**Value**
potential life cycle savings	36 USD
system size	**1kW***
capital cost of the system	**288*** USD
average annual PV power production	367 kWh, 8% of the total system
per kWh PV energy cost	0.065 USD
CO_2 emission reduction in life cycle	about 4 tons ≈ 250 USD
total first year saving in electricity bill	22 USD
total life cycle cost before installing PV	5396 USD
total life cycle cost after installing PV	5360 USD
payback years	13.54 years

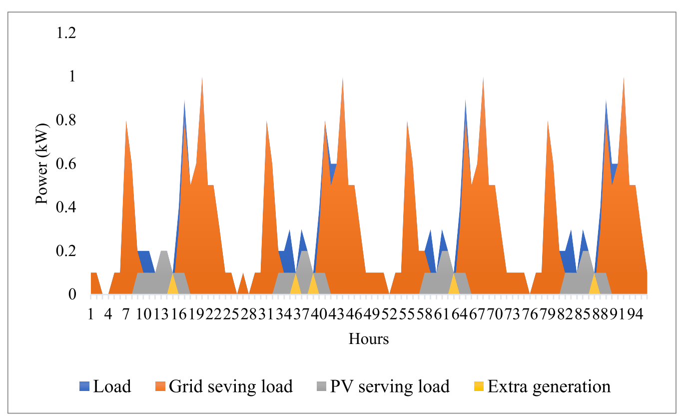

Fig. 7. Power consumption of residential consumer during scenario 1

The outcome summary presented in Table III indicates that most parameters align reasonably well, except for the system size and capital cost. Although the reported system size is 1 kW, it is, in fact, a rounded figure, evident when considering the system's capital cost. Notably, this simulation does not account for incentives, taxes, or financial aid, and the input for the per kW PV capital cost stands at 1200 USD. Consequently, it becomes apparent that 288 USD corresponds to one-fourth of the size of a 1 kW system. REopt's recommended PV size is approximately **250** W, further substantiated by the provided annual PV production value. The reported 367 kWh annual production is consistent with a 250 W system size, rather than a 1 kW system.

D. Scenario 2

Scenario 2 was created with the integration of net metering in mind, enabling surplus electricity generation to be supplied back to the grid. It is noteworthy that although the Bangladeshi government established a net metering guideline policy in 2018, its full implementation remains pending, as indicated in [19]. Nonetheless, we have opted to incorporate net metering into our simulation, extending its application over a 15-year duration.

E. Scenario 3 and 4

Scenario 3 can be seen as an expansion of scenario 2, where scenario 2 focused on a 15-year lifecycle for a PV system with net metering, while scenario 3 examined a 25-year lifecycle.

IV. Small Business

The outcome for scenario 4 is illustrated in Fig. 8, and its findings are presented in Table V.

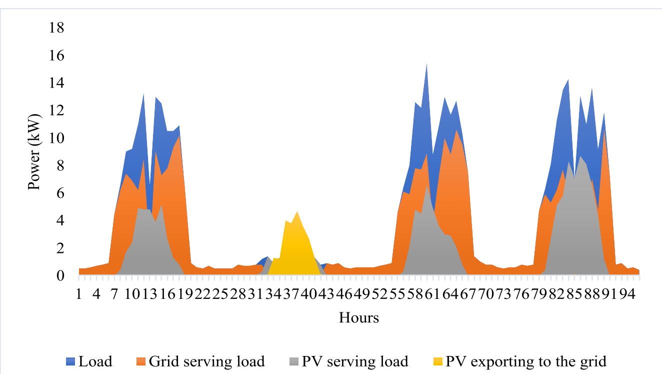

Fig. 8. Power consumption of small business consumer during scenario 4

When a 1kW system is installed, with PV fulfilling both the local load and exporting excess energy to the grid, the economic benefits are evident.

V. Result And Analysis

In this section, we will show the primary output of this study and endeavor to scrutinize the results in accordance with the goals of this research work. In section 3, the various outcomes of the four scenarios we've examined for this study are displayed. We've extracted ten variables from the REopt outcome and exhibited the load profiles associated with those results. Here, we will show a comparative assessment of the results to reach a conclusion.

A. Residential Home Results Comparison

TABLE IV. Comparison of all 4 scenarios of residential simulation

Parameters	Scenario 1	Scenario 2	Scenario 3	Scenario 4
potential life cycle savings (USD)	36	78	1103	**1361**
system size (kW)	**.250**	.650	1	1
capital cost of the system	**288**	834	1200	1020
average annual PV power production (kWh)	367	1,065	**1,495**	**1,495**
average annual PV power production %	8%	25%	**35%**	**35%**
Per kWh PV energy cost (USD)	0.065	0.065	0.047	**0.045**
life cycle CO_2 emission reduction (tons)	4	14	**40**	**40**
CO_2 emission saving cost (USD)	≈ 250	≈ 728	≈ **2003**	≈ **2003**
first year saving in electricity bill (USD)	22	61	**84**	**84**
life cycle cost before installing PV (USD)	**5396**	5396	10163	10163
life cycle cost after installing PV (USD)	**5360**	5318	9060	8802
payback years	**13.54**	13.98	14.68	13.86

Based on this comparison as indicated in Table IV, it can be confidently asserted that scenario 3 and scenario 4 represent the optimal choices for individuals considering the installation of a solar home system (SHS).

B. Small Business Results Comparison

Summary of small business data has been presented in Table V.

TABLE V. Result of all scenarios 4 for small business owner

Parameters	Scenario 1	Scenario 2	Scenario 3	Scenario 4
potential life cycle savings (USD)	6228	10139	34370	**37718**
system size (kW)	13	13	13	13
capital cost of the system	15804	15600	15600	**13260**
average annual PV power production (kWh)	**20,182**	19922	19437	19437
average annual PV power production %	44%	**53%**	52%	52%
Per kWh PV energy cost (USD)	0.065	0.065	0.047	**0.045**
life cycle CO_2 emission reduction (tons)	200 +	250 +	460 +	**460 +**
CO_2 emission saving cost (USD)	≈ 11263	≈ 13618	≈ 26035	≈ **26035**
first year saving in electricity bill (USD)	1433	1635	1681	**1681**
life cycle cost before installing PV (USD)	81129	81129	152,802	152802
life cycle cost after installing PV (USD)	74901	70990	118432	115084
payback years	11.24	9.68	9.4	**8.91**

VI. Conclusion

In summary, this paper employed the REopt lite tool to assess real load data and visually depict the factors hindering the widespread adoption of Solar Home Systems (SHS). From the comparative analysis of the REopt simulation results, we have noted the following findings -

1) For both residential and small village settings, scenario 4 appears to be an appealing approach for SHS installations. Particularly, small businesses can derive significant

benefits from on-site PV installations if suitable spaces are available.

2) Scenario 1 mirrors the present state of our nation. Given the absence of net metering, the installation of large SHS may not be advantageous, as surplus power generated during periods of low demand cannot be effectively utilized or exported without storage capabilities. Consequently, for the residential scenario 1, REopt recommends a rather modest system size of only 250 W.
3) In the context of the business model, even under the current circumstances, the installation of on-site PV can be advantageous. This is primarily due to the alignment of business peak hours with solar peak hours. However, the overall potential for lifetime savings in this case is not particularly appealing, which is the primary reason we do not witness widespread adoption of small-scale on-site PV installations by business farms.

Based on our analysis and existing literature references, we propose the following recommendations for Solar Home Systems (SHS):

- Introduction of net metering within our current renewable policies can be a game changer for both residential and business purposes, as it significantly enhances the economic attractiveness of the system.
- Resident whose monthly electricity consumption is approximately 250 kWh or higher can consider installing on-grid PV, and it will prove to be economically profitable.
- Business users have the opportunity to deploy PV systems and reap benefits under the current policies, as the peak PV generation hours align with business peak electricity demand hours.
- On-site PV installations would become even more appealing to business users if net metering were to become accessible, as most businesses observe a weekly off-day. On this off day, approximately 90% of the electricity generated by the PV could be exported to the grid.
- High initial capital costs can continue to serve as a hurdle for SHS installations. The introduction of improved financial mechanisms will enhance the appeal of SHS.
- The growing awareness of environmental issues will render SHS even more profitable, for not only environmental considerations but also for economic incentives.

While the study's primary limitation lies in the absence of specific studies focusing on similar objectives using REopt, other literature on resilience analysis provides interesting insights. Moreover, the use of rounded system size figures in small-scale analysis is a weakness, but the determination of actual system size based on other data mitigates this concern, as demonstrated in the analysis of residential scenario 1. Although the inclusion of more scenarios and load profiles could strengthen the conclusions, the presented findings sufficiently justify the economic viability analysis of SHS in residential and small business applications. Future research opportunities include investigating clean energy goals, system resilience analysis, and economic viability across different sites.

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