Enhancing Energy Resilience through reducing energy losses from Solar Home System in coastal Bangladesh.

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Abstract

Since 2009, Solar Home Systems (SHS) have been playing a significant role in accessing electricity in poor households, particularly at the remote coastal areas in Bangladesh. A total of 60,37,689 SHS have been installed which are supposed to generate approximately 263.79 MW electricity as per the database of SREDA (2024). However, the present situation of SHS is very poor. There are several known factors contributing to significant energy loss such as poor-quality equipment, wrong installation of PV, poor wiring, using traditional battery, etc. This study investigates these factors to identify energy loss from individual parts of existing SHS, and determined how much total energy, approximately, is being lost. The study also suggests solutions that can reduce energy losses and strategies to enhance energy resilience in the remote coastal communities of Bangladesh. The findings indicated the use of traditional batteries for energy storage of SHS as a common issue. These types of batteries were not only short-lived and harmful for the human and environment but were also responsible for significant energy losses. This study compared LiFepo4 battery as an alternative to traditional batteries to determine potential energy loss. Overall, the study looked for ways to reduce energy loss and enhance the sustainability of SHS which will ultimately ensure energy resilience.

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1. Background

Electricity is the main triggering-force for the social and economic development of Bangladesh which plays a vital role in achieving Vision-2041 as well as succeeding SDGs(Begum, 2021)(Akter, 2022)(Mohammad Mafizur Rahman, 2021) (1,8, 31).In 2014, approximately 76% of the population in Bangladesh did not have access to electricity from the national grid of which most of them lived in rural areas(Akter, A Short Assessment of Renewable Energy for Optimal Sizing of 100% Renewable Energy Based Microgrids in Remote Islands of Developing Countries: A Case Study in Bangladesh, 2022) (2).In the past ten years, the Government achieved significant success in energy generation as well as in extending grid lines to all the corners of the country. However, Load shedding is a regular issue particularly in the rural areas. Because, still the total energy production is not sufficient to fill up the actual energy demand which is increasing more than 10% in a year. Another important issue is the source of the energy production; more than 90% energy is produced from fossil fuelslike coal, oil and natural gas which lead to huge carbon emissions in the atmosphere(Tausif Ali, 2019)(3). Considering these issues the Government of Bangladesh has been working on adopting renewable energy sources in many more ways. Also, the government has committed to generate 4100MW of energy from renewable energy by 2030, which will be at 100% of the total energy demand by 2050(Ministry of Environment)(4-NDC Report). Achieving this high ambitious target is a big challenge for the country. The target of 2015 (5%) and 2020 (10%) are already failed to achieve. (Abdul Hasib Siddique, 2021)(Md. Rejwanur Rashid Mojumdar, 2011)(Begum, 2021)(5, 6 & 31**)** Bangladesh is blessed for its high potentiality of renewable energy resources. In 2014, the Government initiated the establishment of the Sustainable and Renewable Energy Development Authority (SREDA) with the objective of fostering renewable energy (RE) adoption and enhancing energy efficiency to secure a sustainable future for the nation (**7**). The country has a 722.592 MW capacity for renewable energy in March 2021, in which 67.6% coming from solar, 31.84% from hydro, and 0.55% from other energy sources like wind, biogas, and biomass. Over 6 million installed solar power systems produced about 488.662 MW of the total capacity of renewable energy output (7-SREDA). Solar PV system is comparatively better than other renewable resources as per the geographical condition of Bangladesh. Solar energy is an infinite energy resource and is environmentally friendly, clean, green, and is not considered destructive to both plants and animals.

Since 2003, Solar Home System (SHS) has been playing significant role in accessing electricity in the poor household as well as many remote areas in Bangladesh. A total of 6,02,363 SHS has been installed which are generating approximately 262.75 MW electricity as per the report of SREDA-2021. However, there is a big chance of significant energy losses from the SHSs due to poor quality of PV and equipments, traditional energy storage, poor wirings and almost lack of awareness on using and caring of the system. This issue raises the question of reliability and sustainability of the SHSs in Bangladesh which are two important factors of Energy Resilience. Energy resilience means, the ability to avoid, prepare for, minimize, adapt to, and recover from anticipated and unanticipated energy disruptions in order to ensure energy availability and reliability (https://www.eurelectric.org/in-detail/energy-resilience)(Renaldi, 2023)9.AyyoobSharifi explain in his literature review that, Availability, accessibility, Affordability, and Acceptability are the 4 dimensions of energy resilience which must have 4 abilities: Plan/prepare, Absorb, Recover, and Adapt(Ayyoob Sharifi, 2016)(10). Most of these 'abilities' are suffering at all the households particularly in the coastal areas in Bangladesh due to significant load shedding and poor performance of the SHSs.This study investigates the present condition of the SHSs, identifies all the sources from where the energy is lost anddetermines how much energy is being lost every day as well as how the losses can be reduced.

2. Literature Review

710 kilometer coastlines –around 47201km2 areas in 19 districts – approximately 32% of total area of Bangladesh,wherearound 35 million people live(Muhammad Nasir Uddin) (11-M.N Uddin). Ranked as the 7th vulnerable country to climate change, Bangladesh is drasticallythreatened by severe cyclone, floods, land erosion, salinity intrusion and sea level rising and the coastal communities are affected mostly. A higher percentage of people live below the poverty line in this coastal zone and this marginalized group of people are the frontliners of every climatic hazards, while they don't have contribution to the climate change(Abdullah-Al-Mahbub, 2022) (12). There are many remote coastal areas in Bangladesh where grid connection is yet to establish. According to a report of World Bank in 2021, Rural households only have access to grid electricity in about two-thirds of cases and also, there are frequent load shading within those areas(Group, 2022) (13).On the other hand, grid expansion to the remote off-grid areas isn't a good decision in today's world because it increases GHG emissions as most of the energy generation plants in Bangladesh are based on burning fossil fuels(Md Rumi Shammin, 2021) (**14**).

Power generation capacity of Bangladesh has been developed dramatically within the last decade which accounts roughly around 25.5 gigawatts in 2022 from about 5 gigawatts in 2009(Bank, 2021)(15). According to the final report for the financial year 2021-22 of Bangladesh Power Development Board, total power generation capacity in 2021-22 was 85607 Mkwh including hydro (0.87%), solar (0.38%) and imported energy (9.01%), which was 80423 Mkwh in 2020-21.(Board)(16).The Government already announced 100 percent accessibility of electricity from March 2022 (Power and Energ, 2022)(17), which was only about 47% in 2009. According to a report of ADB in 2022, the electricity coverage was 99.5% in July 2021. Despite this successful achievement, still, the reliability and quality of electricity as well as fulfilling the total energy demand remain major issues(ADB, 2022)(18-ADB). As of 2021, Bangladesh's per capita electricity generation stands at 510 kWh, which is notably lower compared to neighboring South Asian countries such as India (1208 kWh) and Sri Lanka (554 kWh) in 2021(Kusay Faisal Al-tabatabaie, 2022) (33). Latest per capita energy generation in Bangladesh is 321 kWh (Shoyeb, 2014)(35). The demand of electricity will be higher more than the current growth rate of electricity demand (10% yearly) due to rapid growth of population, technological development, economical improvement, and increased GDP growth. Also, the per capita electricity consumption of 378 kilowatt-hours (kWh) in fiscal year (FY) 2020 remained notably lower compared to other South Asian countries(ADB, 2022) (18). The updated Power Sector Master Plan (PSMP) 2016 estimates that in 2030 and 2041, respectively, 31,000 MW, and 57,000 MW energy will be needed compared to demands of 27,400 MW, and 51,000 MW (Abdullah-Al-Mahbub, 2022)(12). On the other hand, the non-renewable resources like fossil fuel, natural gases etc. on which most of the energy generation is depended are declining in a fast rate. Globally 64% of energy generation comes from burning fossil fuels which is a big global issue as it emits a lot of greenhouse gases. So, adopting renewable resources for energy generation is a critical societal necessity as it has the potential to decarbonize(Maria McCoy, 2021)(19-Maria McCoy1).Because, Renewable Energy not only addresses the energy crisis but also contributes to poverty reduction and the mitigation of environmental degradation

(Rahman, 2021)(31). Countries all around the world are actively working on how Renewable Energy Sources can be utilized more for generating power with the goals of lowering carbon emissions and improving energy security and affordability(Long, 2018) (20). USA, China, Australia, Netherlands, Belgium, Germany, and India are the great examples who have been doing very well to utilize RE in generating clean energy. Total global energy generating capacity through RE is about 2838GW (in 2020) in which 41.21% from Hydropower, 26.77GW from Solar and 26.17% from Wind and 5.10 from other RE technologies(Abdullah-Al-Mahbub, 2022)(12).

Bangladesh, situated in South Asia, lies between latitudes 20°34' and 26°39' north and longitudes 80°00' and 90°41' east, making it a prime location for harnessing solar energy. Additionally, being a subtropical country, Bangladesh experiences abundant sunlight for approximately 70% of a year, which leads the solar panels to work more effectively. The daily solar radiation ranges from 4 to 6.5 kWh/m², with peak radiation typically occurring in March-April and reaching its lowest levels in December-January(Islam Sharif, 2018) (21). The Ministry of Power, Energy, and Mineral Resources (MoPEMR) developed a strategy for renewable energy in 2008 and defined goals for generating RE resources to satisfy 5, 10, and 100% of total power demand by 2015, 2020, and 2050, respectively(Abdullah-Al-Mahbub, 2022)(Bangladesh, 2016)(12,22). An other words, The Governmenthas set a target to generate 4100MW energy from renewable energy sources by 2030, in which 2277MW from solar, 1000MW from hydropower and 597MW from wind (23).To achieve these targets, there are many strategies, plan, policies and initiatives have been taken by the Government and Non-government organizations in Bangladesh, in which Solar Home System (SHS) is one of the best initiatives which is already praised and recognized by many countries in the World. As of December 2022, the total energy generation from RE is about 949.5MW in which 715.51MW comes from Solar PV(Miskat, 2023) (24). Figure-1 explores the updated data on the total energy generation up to March 2024, which demonstrates that 29286MW is the total energy generation where only 1223.81MW comes from RE (25) and we can see in the figure-2, more than 80% energy comes from Solar Energy among the total RE contribution.

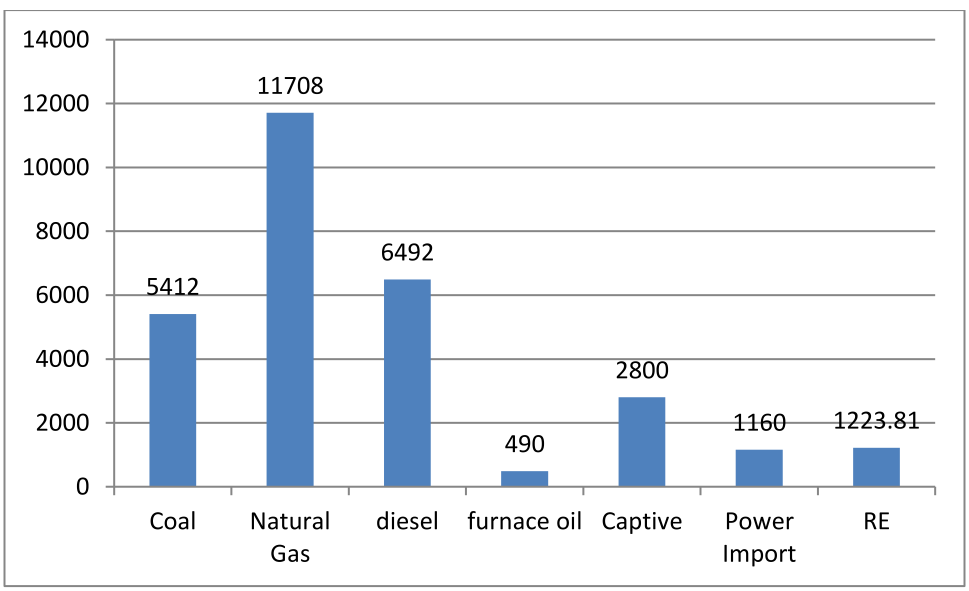


Figure-1: Electricity generation scenario of Bangladesh in March 2024 (MW) (25)

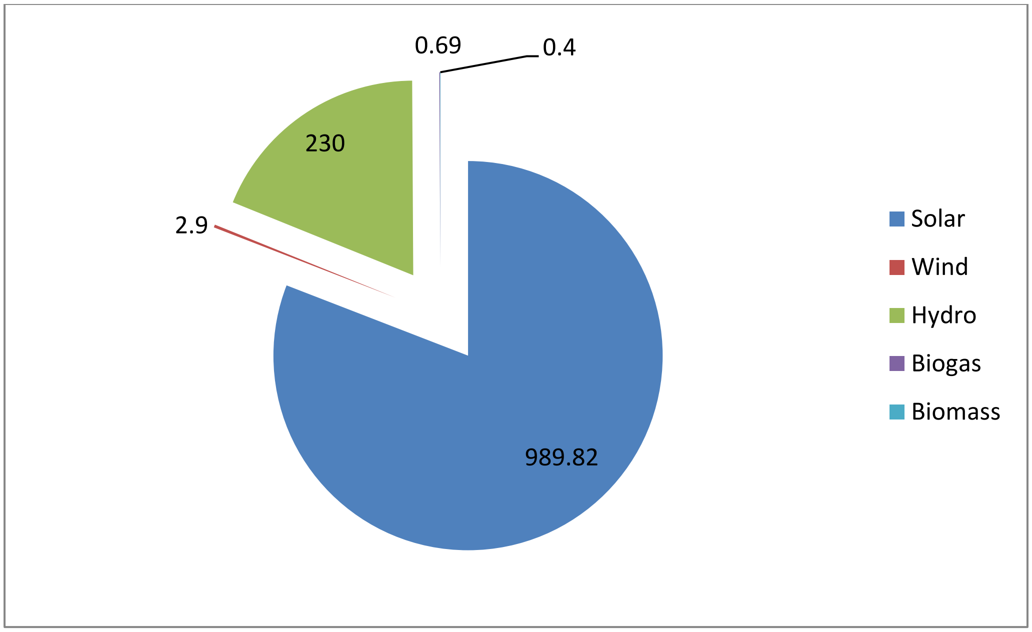


Figure-2: Electricity generation scenario through various RE Technology in March 2024 (MW) (25)

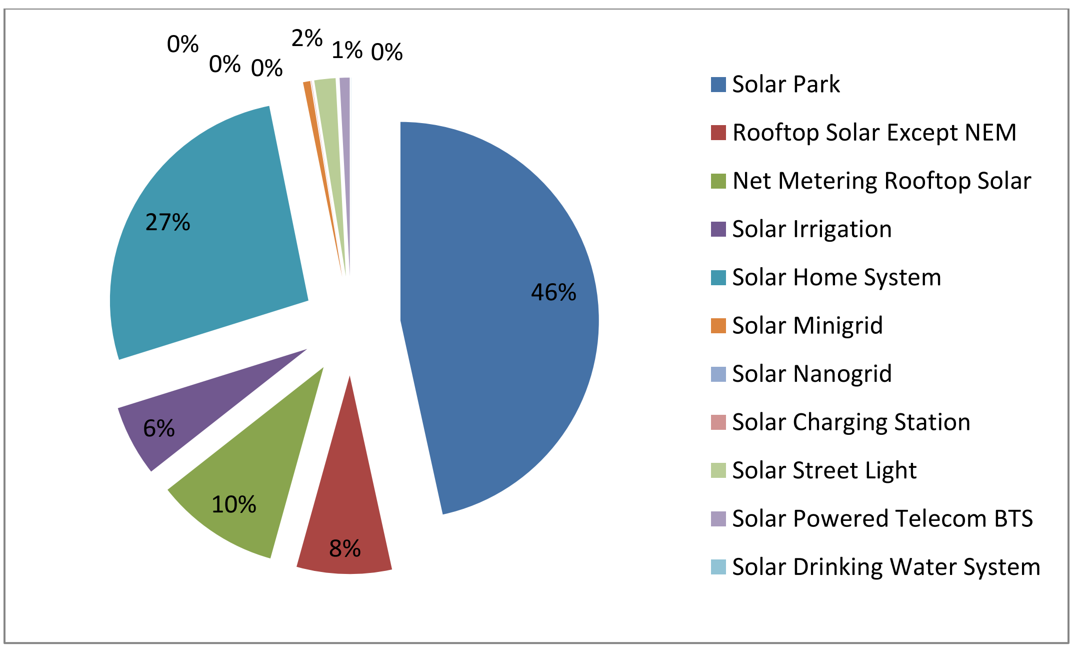
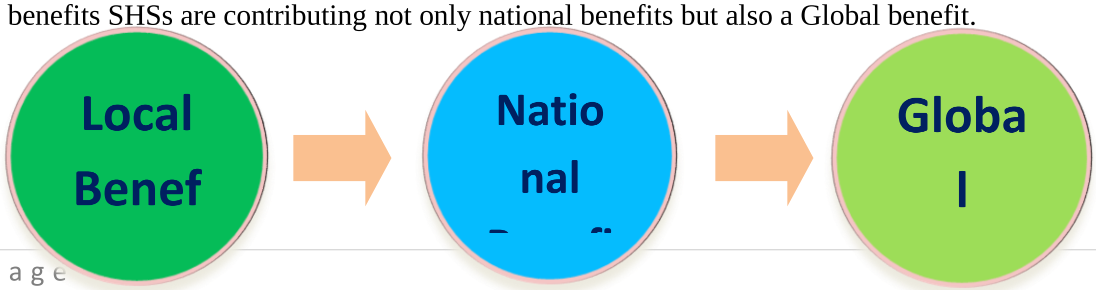


Figure-3: Electricity generation scenario through Solar Technology in March 2024 (MW) (25)

Figure-3 shows that about 27% energy among the all solar technologies is being generated from SHSs, which is about 22% of the total RE contribution. Solar Home System (SHS) is a small off-grid system which is very easy, simple and cost-effective technology for a rural off-grid community. This technology has already been recognized as a "win-win solution" as it has a significant contribution to reduce GHGs as well as to access of electricity to the remote and poor community people (Shammin, 2022)(**14**). The SHS Program of GOB is praised as world's most successful government program for off-grid energy generation which was started in 2003 led by IDCOL- a company that established in 1997 under Bangladesh Bank. The government secured funding for the Solar Home System (SHS) Program through development partners, initially utilizing IDA funds from the World Bank. IDCOL received these funds from the government in local currency to provide refinancing to Partial Organizations (POs) for a portion of the loans extended to SHS customers. The POs distributed SHS to customers on credit, allowing payments to be spread over a period of up to three years, with interest rates ranging from 12 to 16 percent(Shammin, 2022)(Cabraal, 2021)(Miftahul Mobin Chowdhury, 2022) (14, 27, 34). According to SREDA database, about *6,037,689*SHSs have already been installed in the off-grid households which produce 263.79MW electricity. Hundreds of studies have been published where every type of impacts and outcomes of SHSs are investigated thoroughly. Hamidul Haq explored in his paper that SHSs play a vital role in improving the livelihoods of rural impoverished households through increasing physical capital, human capital, financial capital, natural capital, and social capital - especially in the southwestern coastal region of Bangladesh((Huq, 2019)(26). CO2 and black carbon emissions which are responsible for asthma, lung cancer, and infectious diseases, are reduced because SHSs played significant contribution on avoiding kerosene. Between 2003 and 2021, the use of solar home systems (SHS) instead of kerosene has resulted in an estimated avoidance of 9.6 million tonnes of CO2 emissions (Cabraal, 2021)(27). Figure-4 explores core benefits of SHSs that elucidated in the preceding literatures.

Figure-4: Major Benefits of SHSs (14,26,27)

Though these benefits and outcomes were effective mostly during the period 2000 to 2018 until the grid connection, SHSs are still an essential part of each household in the coastal rural areas in Bangladesh as they suffer from regular load shedding for a long time every day. In addition, SHSs ensure the energy resilience principles when the grid connection turned off for couples of days due to storms or cyclones. Enamul explains in his paper that SHSs have a direct and indirect contributions in achieving SDG goal no-3,4,5,7,8,9,10,13,and 16 (Priyankara, 2021)(28). However, all these outcomes are not appropriate for recent days; for instance, nobody uses kerosene nowadays for lighting their homes because grid connection is everywhere now.We have to evaluatecurrent benefits of SHSs in different point of view.As per the Grid Emission Factor (GEF) adopted by the Government of Bangladesh in August 2013 (0.67 ton CO2 per MWh), SHSs reduce (0.67 x 263.79mw x 4.5)= 795.33 ton CO2 every day(Atik, 2022) (29). Beyond the local benefits SHSs are contributing not only national benefits but also a Global benefit.



SHS is hindered by inadequate technology demonstrations, lack of awareness, insufficient media coverage, ineffective promotional campaigns, and a dearth of advertisements showcasing the benefits enjoyed by SHS users. Also, there is a question on ensuring SHS governance because the users can't get the warranty benefits properly from the particular company and they suffered from many technical problems due to ignorance of the service providers. Supplying poor quality of SHS components and lack of local technicians hampered the smooth run of the system and sustainability of the SHSs((Huq, 2019)(Khan, 2020) (26,30).

Above findings are often very common in the existing literatures. During the period from 2005 to 2019, there are seventeen research papers published on what is the current situation of adopting renewable energy in Bangladesh including wind, hydro and all kinds of solar technologies.Several studies published which investigates the challenges and barriers in adopting RE in Bangladesh(Islam Sharif, 2018) (31). However, very few studies found where present condition, sustainability and overall performance of the SHSs are evaluated. Particularly, only couples of studies found where energy loss from this type of installed SHSs are addressed very briefly. So, this is fully unknown that whether the SHSs are still performing good or there is a huge energy loss occurred.This study investigated the present condition and performance of the SHSs in order to ensure whether there is energy loss is really happening or not and how much energy is being lost everyday including the main causes of that loss. This study will be very beneficial to the users, professionals, researchers, and decision makers as the outcomes of this study will explore the small and big holes for which the energy resilience is struggling.

3. Rational

The PV module's location, orientation, and tilt angle significantly affect its performance and shorten its durability. The shading effects on the edges and pillars result in the loss of approximately 18% to 35% of energy(Oufettoul, et al., 2023). (37-HICHAM OUFETTOUL). In her paper, Lina Alhmoud demonstrated the impact of soiling issues, such as snow, dirt, dust, leaves, pollen, and bird droppings, on the energy production of PV panels. Additionally, the study highlighted that the use of substandard cables leads to considerable energy wastage(Alhmoud, 2023) (38-Nina). ESS is another vital issue for energy loss through charge-discharging process of the battery which is an unavoidable loss(Rezaeimozafar, 2022) (39-Mostafa). However, Podder showed in his paper that using Lithium Iron Phosphate battery (LiFePo4) instead of traditional lead acid battery is better alternative for SHSs since this battery can be fully charged within 2-3 hours where conventional battery needs 10-12 hours to be full-charged (Podder & Khan, 2016)(40-Podder). A blog-article of ADB reported that, approximately 30% of the electricity generated by a typical solar home system remains unused because of the standardized battery capacities supplied with the systems(Elbling, 2017) (41-ADB 2017).In another study this is stated that about 40% power loss can be possible due to battery conversion, temperature, power point mismatch, lack of maintenance, and cable loss (Elbling, 2017)(41-2019).Above information raise the following questions:

1) What is the present condition of the globally praised SHS initiatives in Bangladesh?
2) Still the SHSs are contributing its better performance to enhance the energy resilience?

3) How much energy is being lost every day?
4) Which are the reasons behind the losses?
5) What measures can reduce the energy losses?

As depicted in figures 3 and 4, it is evident that since 2003, solar home systems (SHSs) have made significant contributions. These contributions extend beyond individual households, aiding the national government in achieving its energy objectives and also playing a role in mitigating global greenhouse gas emissions.In the same way, energy loss from the SHSs is not only an issue for that particular households, also it is a big loss for the government. For example, if the six million SHSs have only 10% of energy loss, then the total figure of loss will be about 26.28MW for the country in each day. Moreover, any limitations of this technology can hamper achieving the overall success and promotions. So, it is crucial to ensure its performance and sustainability to enhance the energy resilience. There are very few studies on SHSs that investigated into the energy losses. So, it is crucial to identify the energy losses and find out the possible solutions that can reduce the losses as well.

The outcomes of this study will help understand all the gaps through which energy is being lost from SHSs, will open many new insights on how the losses can be reduced, and will explore new path for further research on enhancing the reliability and sustainability of the SHSs, which will ensure the energy resilience to the community.

4. Research Questions and Objectives

The main objective of this research is to identify and reduce energy losses from SHSsinstalled in the coastal zone in Bangladesh. The study aims to investigate the present performance, identify all the possible sources of energy loss, and find potential ways to reduce those losses that can increase the overall performance and efficiency of the SHSs.

Objective:

To measure and identify ways to reduce energy losses from SHSs installed in Bangladesh

Research questions:

1. Approximately how much energy is being lost?
2. What are the sources and reasons of energy losses from SHS?
3. How to reduce the losses and increase the efficiency of SHSs?

5. Research Framework

5.01 Define Energy Loss

"Energy loss," also known as "power loss," denotes the energy dissipated during the transmission of electricity from the power plant to the end user, caused by electrical resistance in the power lines and equipment (Han, 2023)(36-BINGHUI HAN).In this paper, "energy loss" pertains to the shortfall between the expected electricity production from the photovoltaic (PV) system of a specific SHS and the amount of electricity really consumed by the user from that particular SHS.

5.02 Reason and Sources of Energy Loss

There are three main reasons for which energy losses can be occurred:

(1) Technical Faults,

(2) Lack of Maintenance, and

(3) Environmental impacts.

Partial shading, wrong direction, inappropriate tilt angle, poor wirings, poor quality controller, poor condition of battery are considered as the technical faults. Lack of maintenance includes dusty and dirty PV panel, poor wire joints, poor connectors, insufficient water in the battery, etc. High temperature is one of the vital environmental impacts which is responsible for energy loss. More than 25 C temperature leads to decrease the energy production of a PV. Other environmental facts such as bad weather, storms, variation of solar irradiance, etc. that have impacts on energy production also. However, environmental facts for energy losses aren't focused in this study because most of the environmental impacts are unavoidable. Furthermore, there are few more facts that responsible for energy losses such as PV degradation loss, non-branded PV panels, etc. which aren't considered in this paper.

5.03 Ways to reduce Energy Loss

Regular Maintenance is essential for any kinds of technical systems like Solar Home Systems. The panels should be cleaned always for generating electricity efficiently. Most of the SHS users particularly who live in a remote coastal zone in Bangladesh don't have even a little knowledge on how regular maintenance can increase its life span as well as performance. This study explores all the potential ways through which the energy loss can be reduced.

Indicators	Quantification	Procedures	Reference
Research component: Identify Energy Loss			
- Expected PV Output	- Survey - Observation	Rated Capacity x Solar Hours/day (GSA)	
- Actual PV output	- Output Test of PV	Measurement of Volt and Ampere Pmax = Vmax x Imax	52, 53
- Daily Consumption	- Survey - Load Test	Total load/day (solar appliances x daily usage hours)	
Research Component: Reasons& Sources of Loss			
(Technical Issues) - Direction of PV installed - Tilt angle of the PV	- Household Survey - Physical observation - KII	- Semi-structured questionnaire - Questionnaire for KII	

- Condition of Wiring - Condition of Connections - Condition of Controller - Condition of Battery	- Practical Test	- Select 2 different SHSs, mitigate technical faults and observe for 10 days.	
(Lack of Maintenance) - Cleanliness of the PV - Cleanliness of Controller - Cleanliness of Battery - Water level of Battery - Repair of Battery - Visit by service provider	- Household Survey - Physical observation - KII - Practical Test	- Semi-structured questionnaire - Questionnaire for KII - Select 2 different SHSs, mitigate technical faults and observe for 10 days.	
Research Component: Way to reduce loss			
- Mitigate technical issues - Awareness raising on SHS - Policy	- KII - Practical Test	- Questionnaire for KII - Select 2 different SHSs, mitigate technical faults and observe for 10 days.	

Table-1: Indicator, quantification and procedures.

5. Materials and Method

This research has been followed by both quantitative and qualitative methods.A practical test was conducted in two selected households to determine whether the solutions is working or not, which type of battery is best for reducing losses and how much energy can be reduced eventually. Though most of the previous studies related to performance evaluation of the solar PV were conducted through various solar simulation software and web data, such as Homer pro, GSA, NASA etc, this research was conducted just based on practical test and experiment through measuring necessary technical parameters, observing physical condition, and information provided by the SHS users. Furthermore, any kind of complex mathematical analysis was avoided in this study. There are three reasons behind avoiding the software and traditional complex analysis, which are: (1) to make the paper as simpler as a non-technical person can understand easily. Because thousands of non-technical persons are involved in this field particularly in Bangladesh, (2) very few solar technicians have the adequate knowledge on how to use those software as well as understand complex scientific analysis. (3) Data from practical test is more reliable, accurate.

Figure-5: Steps of the research

6.01 Used Materials:

Several electrical tools were used during the field study to measure the actual condition of each and every SHSs, those are: Digital Multi-meter, Load Appliances, 12v 30ah Lithium Phosphate Battery, 12v 30ah Lead Acid Battery, Digital Volt Meter, Digital Compass, Digital Tilt Tracker, Screw Driver, Electric tester, Black tape, Wires, etc.

6.02 Study Area:

Shyamnagar is the bigger Upazilla of Satkhira District in Bangladesh that located in the south-western zone in the country. Burigoalini Union of Shyamnagar is one of the biggest coastal zones affected by climate change of which 3 villages were selected for this study.

There are five major reasons that why Burigoalini Union was selected for this study: Firstly, about 21.6% of total SHSs were installed in Satkhira District and the Burigoalini Union is one of the area which have a 100% coverage of SHS. 2ndly, this union is located in the remote off-grid coastal zone. Most of the people are under extreme poverty. So, it will be easier to identify that whether they are able to buy SHS components or not. Thirdly, older SHSs can be observed in that area because people are habitual with SHS here from 2000. Fourthly, this area has a very good solar radiation that has more potential for generating solar energy. Fifthly, according to a World Bank report coastal off-grid communities are the most benefited area for SHSs where people improved their livelihood adopting SHSs. Hence, this study can be a very good assessment on whether the benefits are still secured or not.

6.03 Data Collection

Secondary data was collected from literatures, articles, various news portals, documents of various departments and so on. For primary data, three remote villages of Shyamnagar Upazila under Satkhira District were selected as a case study site. Practical test and technical measurement was made to identify the energy losses. Basic information, daily energy demand and consumption, daily loads from grid electricity, SHS loads and their duration, measured technical data of SHS and other related information were collected through a semi-structured questionnaire in a random basis from 300 households who have SHSs installed in their home.

6.04 Data Analysis

Energy output from a solar PV almost depends on several factors and influences including location, latitude, elevation, seasons, measurement time, cloud cover, and other industrial and meteorological parameters and conditions, solar irradiance, tilt-angle, shading, module temperature, fill-factor, material degradation, soiling, PID, parasitic resistances and many other things. (43). STC is a recognized PV testing criteria that has 2 different conditions: firstly the solar irradiance has to be 1000w/m2 and the cell temperature has to be 25^0C. However, this method is appropriate for industrial indoor testing (43). For a comparative analysis of PV output, it is essential to fix an expected output that should come from a PV. Many studies considered output data directly from NASA or GSA site where it was demonstrated that the average solar radiation is between 4-6.5 kwh/m2 per day while the sunny hours varies from 6.5 to 10 hrs per day (44,45,46,47, 48, 49 & 50). However, this is just an annual average for the whole country - not for a specific location, and also, there are variations found in different literatures. On the other hand, considering rated Voltage and Ampere of a particular PV is not appropriate for that analysis because there are several factors such as how much older the PV is. Generally, PV outputs degrade 0.5%-1% per year according to its quality and efficiency. So, this is very complex and difficult to assess and determine whether a PV installed in a particular location is performing the best output or not. In this study, GSA PV output rate "4.007kwh/kwh/day" was used which is stored in GSA website as the average daily output rate for Shyamnagar Upazila area. As per this rate, measured solar output was multiplied by 4.007 to calculate the expected and actual solar output per day: That means, if a 30w PV can generate 15w during the measurement, then the total energy generation in that day will be calculated as 15w x 4.007 hour = 60.105 WH, where the expected energy generation is 30w x 4.007 hour = 120.21WH. Here the loss of energy will be 50%.

Further, this calculation can help determine just an average rate of energy loss. For this reason, practical test played important role in this study to better understand the energy output and determine the ways that can reduce the losses.

Other survey data like cleanliness of the PV, controller, and battery, shading effects, right or wrong direction of the PV, daily loads etc all are analyzed in a simple way in the excel sheet to determine the sources of energy losses. The analysis was made for each power of SHSs differently to understand the comparison that which group of SHSs is more efficient, which capacity of SHSs is losing more energy.

6.05 Identify Energy Losses

Identifying and analyzing energy loss from a solar system with a very good accuracy is so much difficult, which needs a deep observation on its activities for a long time (54). Most of the studies about analyzing energy loss are conducted with yearlong continuous observation in a single mini or micro grid or a small rooftop solar. Evaluate hundreds of nano grid home solar system is more difficult than experimenting in a mini or micro grid.For identifying Energy loss following two ways has been applied:

6.05.1 Household survey:

During the survey the household owners were asked how many and what types of solar appliances they have, and how many hours they operate those appliances. This information made the total daily loads from the SHSs they consume in each sunny day. Thus, the overall energy loss was identified through deducting the daily consumed energy (WH) from the expected daily energy output from the SHS. For instance, if a household has 20w SHS and the daily consume is 50wh, then the energy loss will be:

Energy Loss = (Expected Energy Generation – Energy consumed by the User)

= (20w x 4.007 hours) – 50wh (watt hour)

= 80.14wh – 50wh

= 30.14wh (lost energy)

In the above calculation the expected average solar hour (4.007 hours) was taken from the Global Solar Atlas data. Accordingly, expected average solar energy output is supposed to be 80.14wh in a full sunny day. So, the total loss from that particular SHS will be 30.14 WH per day. However, this is the total loss including some unavoidable system losses like 7-9% temperature loss, 1-2% cable loss, etc.

6.05.2 Technical Measurement

Beyond the questionnaire survey, every components of each SHS were measured through the machinery tools like digital multimeter, digital DC volt meter etc. Through this way it was identified that how much energy output produced from the PV panel is going to the battery.

This technical measurement was conducted on fully sunny days during 11.00pm to 2:00pm which is considered as solar pick hour. During the data analysis the energy loss was determined in the following way:

Pmax = Vmax x Imax

Vmax = Voltage at the maximum power point

Imax = Current at the maximum power point

Average Measured PV Output (WH) = Pmax x 4.007 hours

Average Expected PV Output (WH) = Rated Pmax x 4.007 hours

Loss from PV (WH) = Average Expected PV output (WH) – Average Measured PV output (WH)

According to the above method, expected energy output (WH) from the PV was determined through multiplying the rated capacity of the PV by 4.007 which is the average solar hour for the area of Burigoalini Union as per Global Solar Atlas. To determine the Present PV output, Vmax and Imax were measured which were multiplied by 4.011 hours. That means, expected energy output of a 100w PV should be 100 x 4.011 = 401.1 WH. Now, after taking measurement if it is found that the panel produces 14 volt and 4 Ampere current then the average output will be 14 x 4 x 4.011 hours = 224.62 WH. So, the loss from the PV system is 401.10 – 224.62 = 176.48 WH in each sunny day. This 224.62 WH energy go to the energy storage system (battery) and if the total SHS consumption is 150 WH, then about 74.62 Wh energy is being lost through the charge-discharging process of the battery.

6.06 Determine the Sources of Energy Loss

6.06.1 Checking PV

Since the solar panel is the main component of the SHS which generates energy, all the PV panels were checked properly whether there is any issue such as partial shading effects, wrong direction of installation, and/or inappropriate tilt angle impacting or not. Also, cleanliness and connections of the panel was investigate carefully.

6.06.2 Checking Wirings

Wiring is a vital issue for energy losses. Poor quality cable is responsible for huge losses. Further, also it was checked whether there is any bad joints in the wiring or any other connection faults.

6.06.3 Checking Controller

During the household survey it was checked that there is a good quality controller installed or not, how well the controller is working, and the connections are satisfied or not.

6.06.4 Checking Battery

Batteries were checked by the multimeter and DC volt meter to determine that the battery is working well. Also, the connections, water level and cleanliness were checked properly. To understand the actual condition of the battery sufficient load as per battery capacity was applied.

5.1. Ways to Reduce Energy Losses

To determine the ways to reduce energy losses from the SHSs two different methods were applied: (1) Practical Test, and (2) In-depth Interview of Key Professionals (KII).

6.07.1 Practical Test

A practical experiment was conducted at holding no-956 under Burigoalini Union. The HH owner is a night guard of Burigoalini Union Parishad Office. This household was selected for the test work depending on three major reasons: firstly, the owner has two different SHSs in which one 30wp system he has been using for his house and another 40wp SHS is turned off for damaged battery and controller. Secondly, the person has technical knowledge about SHSs and thirdly, the location is very good to communicate regular. 67% of energy loss was found during the survey period due to poor wiring, bad connections and dusty PV panel. All the faults of that both systems were anticipated before conducting the test work such as repairing the connection faults, cleaning the panel, set up the panel in a right direction etc. A 30ah lithium phosphate battery pack was installed with the 30wp SHS.A new Volvo branded 30ah lead acid flooded battery was installed with another SHS which was turned off. Both the SHSs were trialed for 10 days to observe the actual PV output, charge-discharge efficiency, and how much energy loss can be reduced as well.

6.07.2 Key Informant Interview (KII)

In-depth interview was conducted with two Key Professionals who have vast experience on solar system. Among them one is a Professor of Bangladesh University of Engineering and Technology (BUET) and another person is a researcher and Country Manager of a multi-national Organization in Dhaka.

7. Results and Discussion

Total 285 households were visited among two villages (East Durgabati and West Durgabati) of Burigoalini Union. All the components of SHSs have been experimented thoroughly during the household survey in order to identify why and how much power losses are occurring. Out of the 285 households, 263 households found with active SHS (92%) and 22 households (8%) found with inactive SHSs. Table-1 shows thatmost of the SHSs are turned off due to connection faults and damaged battery. There are few damaged cells found inside the panels at 6 HHs. Out of the 22 inactive SHSs 6 SHSs were received free of cost from the Government's KABIKHA project. The study found that many SHSs which were installed within 1998 to 2005, still operating with a good condition. Finally 263 active SHSs have been deeply analyzed to find the gaps from where the energy is being lost.

Year of Installation	Capacity (WP)	Reason for turned off	Cash/Installment	Survey no.
2020	40	Cell damaged and battery damaged	Cash	38
2019	40	Turned off due to no battery backup	Installment	14
2017	50	Turned off due to no battery backup	Cash	123
2016	20	Connection fault, battery damaged	Free TR	17
2015	100	Connection fault, battery damaged	Cash	212
2015	65	Connection fault, battery damaged	Cash	213
2013	20	Connection fault, battery damaged	Free TR	18
2013	40	Cell damaged, battery sold	Installment	49
2013	50	Connection fault, battery damaged	Installment	200
2011	20	Connection fault, battery damaged	Cash	9
2009	20	Connection fault, battery sold	Cash	24
2009	40	Connection fault, battery damaged	Installment	145
2008	30	Connection fault, battery damaged	Free TR	98
2008	50	Cell damaged, battery sold	Free TR	112
2007	30	Cell damaged, battery sold	Installment	105
2007	30	Connection fault, battery damaged	Free TR	153
2007	85	Connection fault, battery damaged	Cash	204
2004	50	Cell damaged, battery damaged	Installment	76
2003	50	Cell damaged	Free TR	134
2002	50	Cell damaged	Cash	140
2000	40	Cell damaged	Installment	143
2000	40	Connection fault, battery damaged	Installment	172

Table-2: Fully inactive/turned off SHSs out of 285 households.

7.01 Daily Usage:

7.01.1 From Grid Connection:

National gridline connection was established in the three villages of Burigoalini Union during the year 2018 and 2019. Before that the villagers were depend on only SHSs. The study found that, more than 50% of the HHs didn't need grid connection as their daily usage is very low. Average daily usage of grid electricity of a household is about 1.207 kwh (unit).

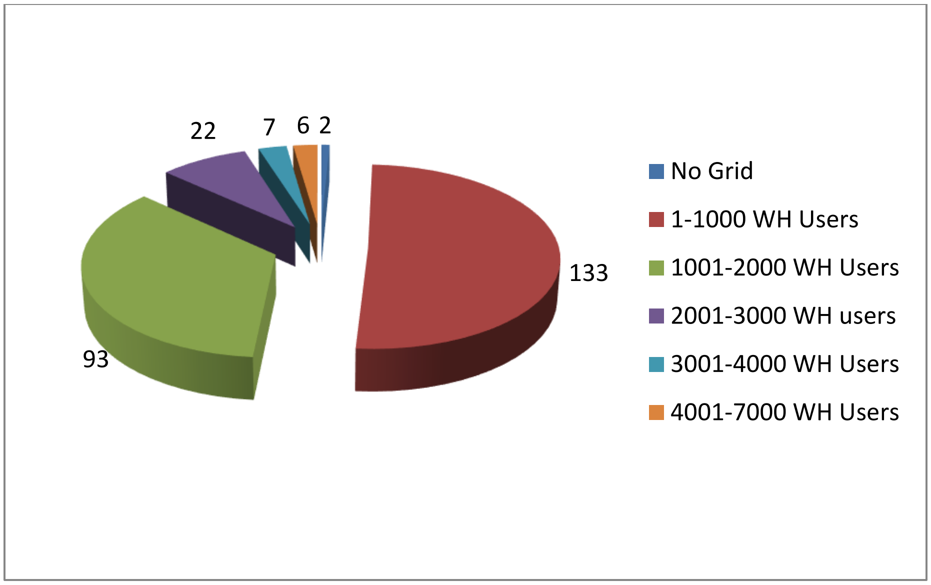


Figure-6: Daily energy usage of HH from grid connection (1000 watt hour = 1 kwh**)**

Figure-6 illustrates that 51% of households (88 households) consume a maximum of one unit per day for their daily energy needs. These households typically utilize 4-5 lights, 2 table fans, and a LED TV. Numbers of households who need 1 to 2 unit energy per day is approximately 35% (93 households). Only 2 households found who don't have grid connection and only 6 households (2% of visited HHs) need 4 to 7 unit of energy per day. Only 7 households found where 3 to 4 unit energy is needed every day.

It would be more advantageous for them to consider expanding their solar home system (SHS) capacity instead of opting for grid line connections. A modest 200Wp SHS would suffice to meet their daily energy requirements. Furthermore, households typically incurexpenses ranging from 5,000 to 7,000 BDT when obtaining a grid connection, which includes service charges, wiring, and other associated equipment costs. Many homeowners express dissatisfaction with grid connections due to frequent daily power outages and high monthly electricity bills.

7.01.2 From SHS Connection:

While more than 99% of households are connected to the national grid electricity, each household possesses its own solar home system which remain essential due to prolonged periods of load shedding. Additionally, adverse weather conditions occasionally result in complete disconnection from the grid electricity for 1-3 days. During such instances, SHSs play a critical role in ensuring energy resilience. However, the study reveals significant negligence and lack of attention towards SHSs, particularly after households have gained access to grid electricity.

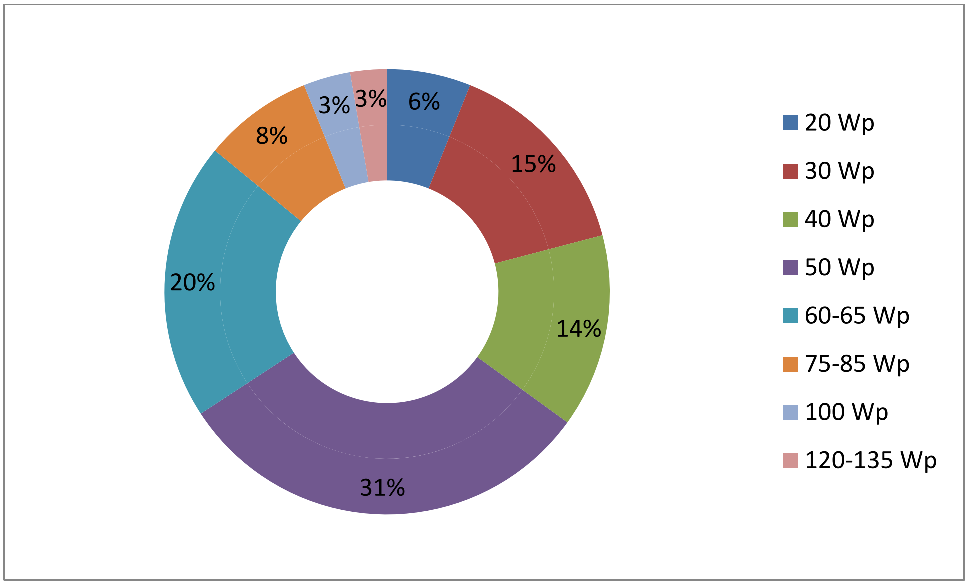


Figure-7: Daily energy usage of HH from SHSs

SHS Capacity	HHs	Percentage	Expected WH/day	Actual Usage/day	Energy Loss (WH)/day	% of Loss
20 Wp	16	6%	1,283.20	447.00	836.20	65.2%
30 Wp	39	15%	4,691.70	1,817.50	2,874.20	61.3%
40 Wp	37	14%	5,934.80	2,425.00	3,509.80	59.1%
50 Wp	81	31%	16,240.50	6,656.00	9,584.50	59.0%
60-65 Wp	53	20%	13,473.60	5,163.00	8,310.60	61.7%
75-85 Wp	21	8%	6,796.95	3,065.00	3,731.95	54.9%
100 Wp	9	3%	3,609.00	1,746.00	1,863.00	51.6%
120-135 Wp	7	3%	3,929.80	2,075.00	1,854.80	47.2%
	263	100%	55,959.55	23,394.50	32,565.05	58.19%

Table-3: Energy Usage and Loss from 263 SHSs.

Figure-7 reveals that 81 out of 263 households (31%) are equipped with 50Wp systems, while only 7 households (3%) utilize systems exceeding 100Wp. Further analysis indicates that approximately 66% of households rely on 20-50Wp systems, 20% utilize 60-65Wp systems, and merely 14% have installed 75-135Wp solar home systems (SHSs). Those utilizing 20-30Wp SHSs can operate a single 10-15W table fan for 8-12 hours daily, along with a couple of LED lights for 3-5 hours each day. However, actual usage patterns differ from anticipated levels. Table-3 illustrates a considerable underutilization of energy generated by SHSs. For instance, 11 units of 20W SHSs are expected to contribute approximately 1.29 kWh of energy daily, yet households utilize only 447Wh, representing roughly 35% of the anticipated energy output. Notably, prior to grid connection in 2019, these smaller SHSs served as the primary energy source for households, with many homeowners attesting to their exceptional performance. Table-3 further indicates an average energy loss of 58.19%, a figure derived from comparing practical energy outputas per their regular energy usage with the expected outputs. As per the table-3, total expected energy output from the 263 SHSs should be 56 kwh approximately where the actual usage is only less than 24 kwh. It's important to note that this represents total loss, including certain inevitable factors such as DC cable loss, charge-discharge processes, panel aging, and temperature variations etc. Throughout this study, meticulous observation identified various potential sources of energy loss, including::

01) Layers of Dust inside the PV
02) Shading over the PV
03) Inappropriate tilt angle
04) Wrong direction of PV
05) Low quality cable
06) Open and loose connections
07) Damaged/Disconnected Controller
08) Low quality controller
09) Insufficient Storage/Damaged battery
10) Lack of Knowledge

7.02 Solar Panel:

Each photovoltaic (PV) panel underwent precise measurements using digital multi-meters, digital compasses, and digital tilt angle trackers. Observations included assessing the cleanliness of panels, the extent of dust accumulation, cleaning frequency, and any potential shading effects. The investigation revealed a significant amount of energy loss originating from the PV panels, as detailed in Table-4 below.

SHS Capacity	HHs	%	Expected WH/day	Measured Energy (WH) /day	Energy Loss (WH)/day	% of Loss
20 Wp	16	6%		638.38	644.82	50.25%
30 Wp	39	15%		2,359.20	2,332.50	49.72%
40 Wp	37	14%		3,015.51	2,919.29	49.19%
50 Wp	81	31%		8,419.82	7,820.68	48.16%
60-65 Wp	53	20%		6,627.78	6,845.82	50.81%
75-85 Wp	21	8%		3,817.71	2,979.24	43.83%
100 Wp	9	3%		2,186.64	1,422.36	39.41%
120-135 Wp	7	3%		2,457.70	1,472.10	37.46%
	263	100		29,522.74	26,436.81	47.24%

Table-4: Comparison of expected energy and genuine output from PV Panels

Table 4 indicates that approximately 47.24% of energy, equivalent to 26,436.81 watt-hours, is lost daily from the solar PVs of 263 households, representing nearly 58% of the total energy loss elucidated in Table-3. Additionally, the study discerned that larger capacity photovoltaic (PV) systems (100-165Wp) experience comparatively lower average energy losses compared to smaller capacity systems (20-65Wp). Among the different capacity ranges, PV systems rated at 60-65Wp exhibit the highest average energy loss, while those rated at 120-135Wp demonstrates the least loss. The primary factors contributing to energy loss from the PVs include the presence of multiple layers of dust, suboptimal tilt angles, incorrect orientations, inadequate wiring, and poor connections.

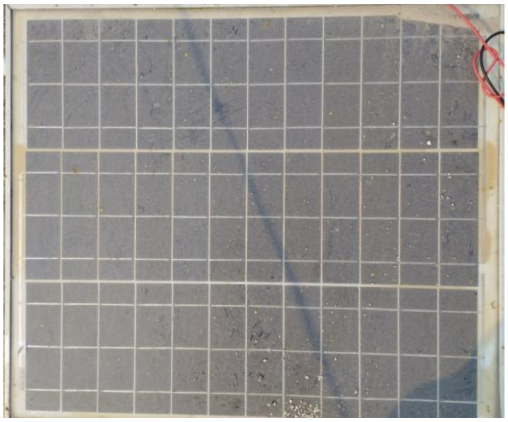
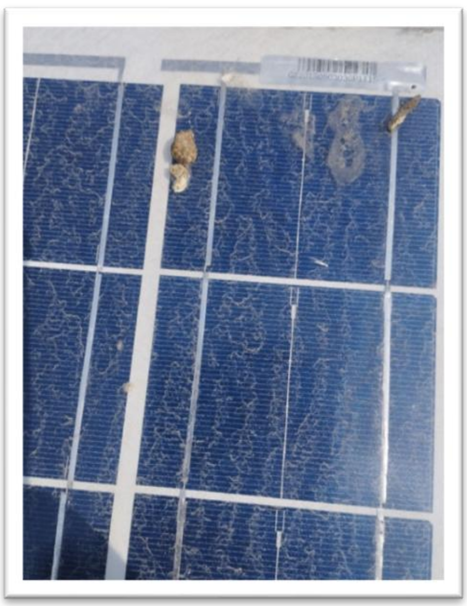


Figure-8 illustrates that the cleanliness of photovoltaic (PV) panels varies significantly across different wattage categories. Specifically, only 25% of 20Wp PVs are observed to be clean, while the percentage rises to 35-46% for PVs ranging from 40 to 65Wp. Notably, larger PVs exhibit higher cleanliness rates compared to smaller ones. For instance, 62% of 75-85Wp PVs are cleaned, albeit the number of such PVs is limited to 18 out of 263. Between 17% and 46% of PVs of various capacities are found to have a single layer of dust, indicating that these panels are not cleaned regularly, with intervals extending beyond a month or two. Moreover, 11% to 25% of PVs of various power are hindered in energy production due to the presence of multiple layers of dust accumulation. On average, the data analysis reveals that 39.54% of PVs are cleaned, 32.70% have a single layer of dust, and 27.76% are in poor condition with several layers of dust. The study highlights a significant lack of awareness and negligence regarding the regular cleaning of PV panels. Many households were identified where PV panels are seldom cleaned, with some relying on rainfall to naturally cleanse the panels.



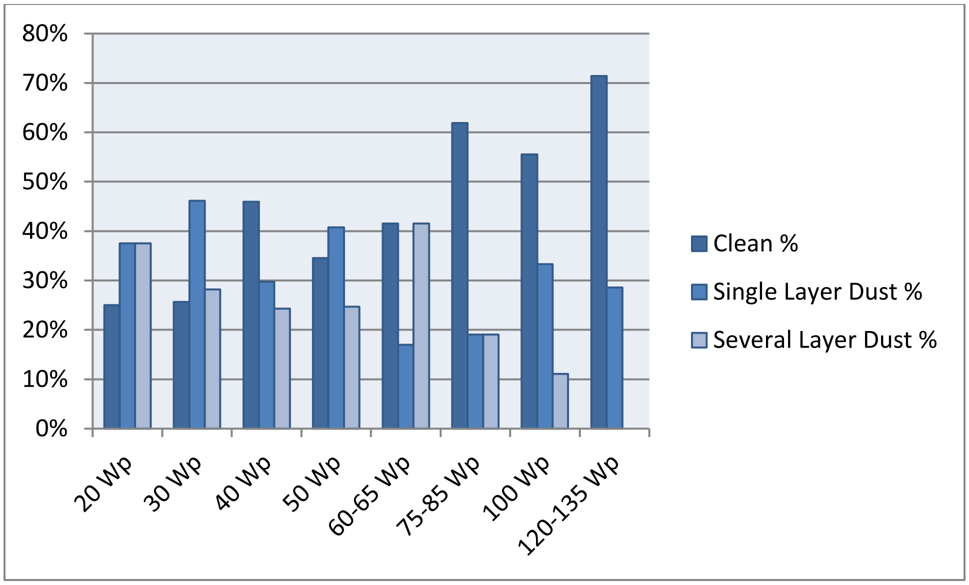


Figure-8: Cleanliness of PVs

For getting a better output from a PV, installing the PV in right direction with an appropriate tilt angle is a very important factor. Energy output can be varied by 10-40% for these factors. Unfortunately more than half of the HHs is found where PVs are installed in wrong direction orinappropriate tilt angle. 142 PVs (54%) out of 263 are found in inappropriate direction and/or tilt angle which is responsible for a significant amount of energy loss (figure-9).

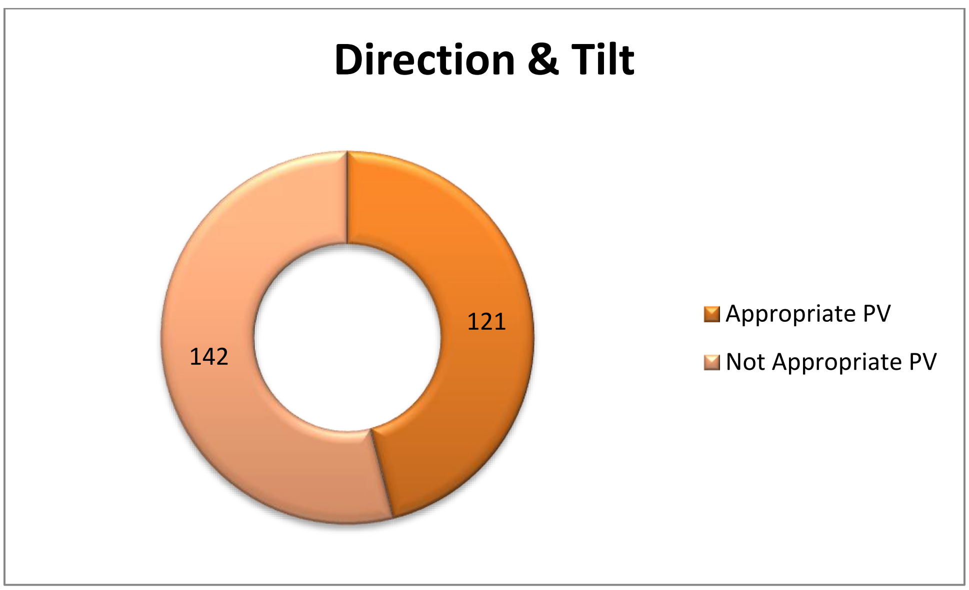


Figure-9: Panel Installation direction and Tilt angel

Table-5 shows that, how many PVs from what capacities are appropriate and not appropriate with the direction and tilt angle. At the study area, most of the households are building with tin shed (Galvanized Iron Sheet) roof and all the PV panels are installed over their roof aligning with it. Very few roofs are placed directly facing or backing the south direction. As a result, most of the installed PVs are not in appropriate direction and tilt angle.

PV Capacity	Appropriate		Not Appropriate	
	SHSs	%	SHSs	%
20 Wp	8	3%	8	3%
30 Wp	15	6%	24	9%
40 Wp	17	6%	20	8%
50 Wp	36	14%	45	17%
60-65 Wp	21	8%	32	12%
75-85 Wp	15	6%	6	2%
100 Wp	5	2%	4	2%
120-135 Wp	4	2%	3	1%
Total	121	46%	142	54%

Table-5: Direction and Tilt angle of PV panel

Shading effect is another crucial issue that decreases the energy production at a high level. Shading effects can decrease the output of a PV panel at 10% to 80%. Many PV panels are found in the study which has up to 60% shading over it because of a tree or its branches. People think that smaller shading is not a big problem to produce energy from the solar. However, only 10% of shading effects can drop down up to 30% production.

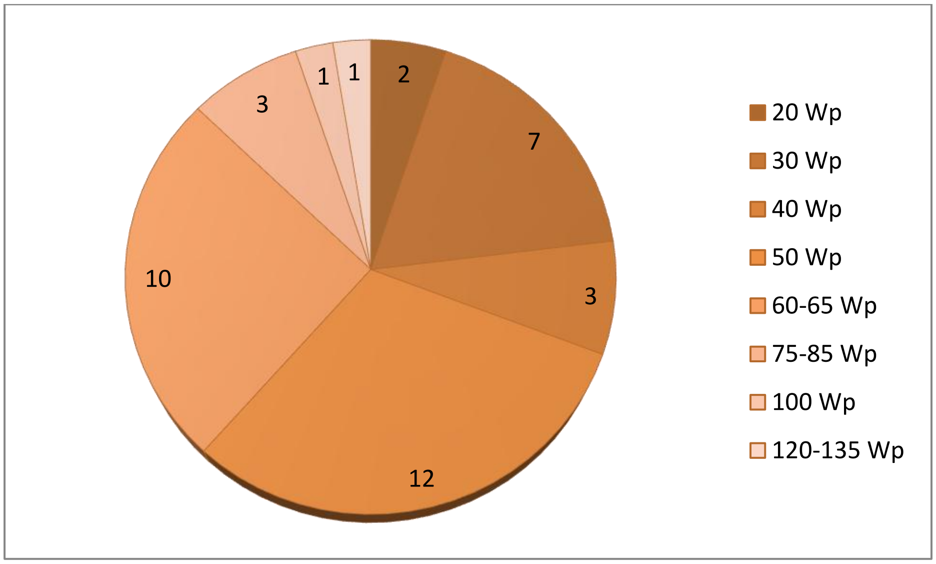


Figure-10: PVs that have shading effects

Out of 263 SHSs 39 PVs have shading effects which is 15% of the total surveyed HHs. Maximum energy loss is found in this 15% of SHSs due to the shading effects. Maximum energy loss is found in survey no 99 where significant shading effect was observed. 84% of energy loss is found from that PV panel.

One important factor of energy loss from SHSs is poor cable and wiring through which about 2% to 20% loss can be occurred. Generally, 2% loss is common and unavoidable for cable and wiring. But, above 2% loss is occurred when poor quality cables are used, any loose connections are happening in the cable particularly that cable which is connected with the junction box of the PV to the controller or Battery. Sometimes, the loss is increased more when the distance from the PV to controller is too long.

PV Capacity	Connections					
	Good		Not Good		Poor	
	SHSs	%	SHSs	%	SHSs	%
20 Wp	3	19%	6	38%	7	44%
30 Wp	7	18%	17	44%	15	38%
40 Wp	16	43%	17	46%	4	11%
50 Wp	25	31%	37	46%	19	23%
60-65 Wp	22	42%	20	38%	11	21%
75-85 Wp	8	38%	9	43%	4	19%
100 Wp	3	33%	4	44%	2	22%
120-135 Wp	5	13%	2	29%	0	0%
Total	89	33.84%	112	42.59%	62	23.57%

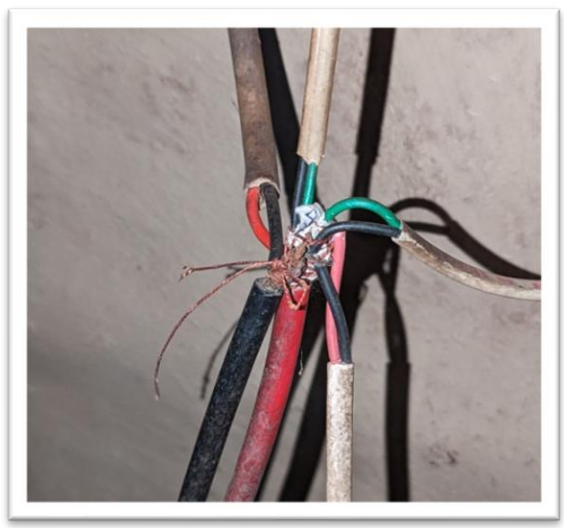
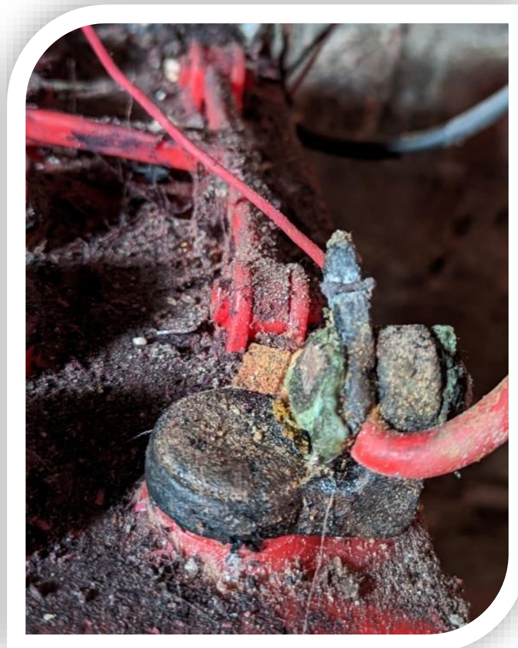


Table-6: Connections of PV Panels to Controller and/or Battery

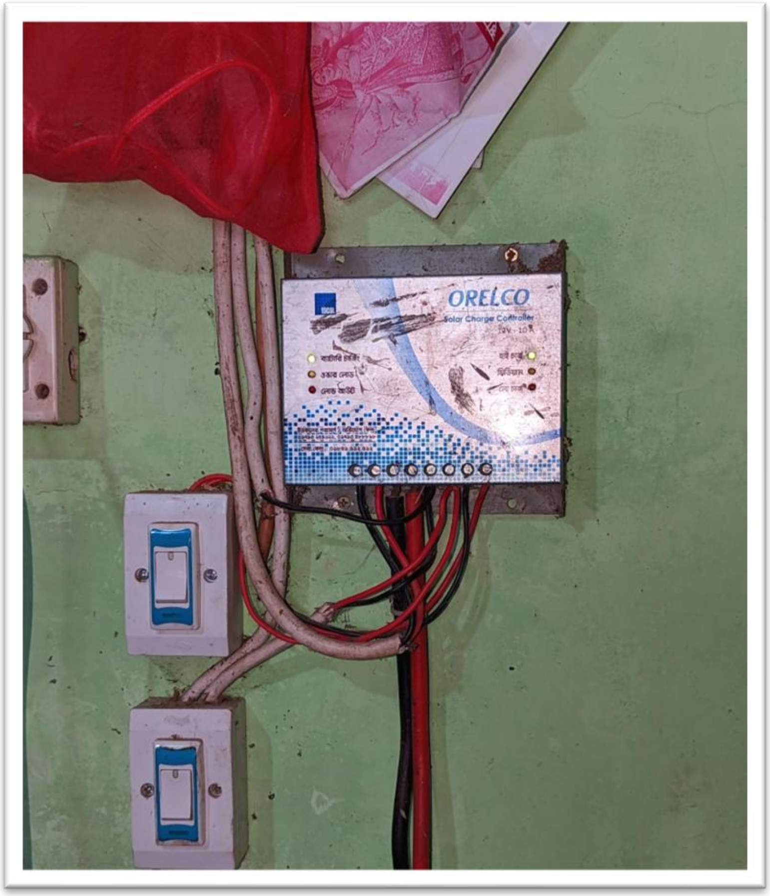
Table-6 demonstrates that only 34% of SHSs have a very good connection while more than 42% connections are not good and rest 23% of connections are very poor. There are many loose connections and open wire found which are responsible for energy loss. Table-6 shows that 25% SHSs are found with good wiring but 56% wiring are not good and 19% SHSs have a very poor wiring.



PV Capacity	Wiring					
	Good		Not Good		Poor	
	SHSs	%	SHSs	%	SHSs	%
20 Wp	2	13%	9	56%	5	31%
30 Wp	5	13%	23	59%	11	28%
40 Wp	12	32%	21	57%	4	11%
50 Wp	16	20%	50	62%	15	19%
60-65 Wp	18	34%	24	45%	11	21%
75-85 Wp	7	33%	11	52%	3	14%
100 Wp	1	11%	7	78%	1	11%
120-135 Wp	5	71%	2	29%	0	0%
Total	66	25%	147	56%	50	19%

Table-7: Wiring of PV Panels to Controller and/or Battery

7.03 Controller:



A solar charge controller plays vital role to ensure better management of the SHSs as this component works as a bridge between PV, ESS and appliances. This is essential for securing the battery health as well as longevity of solar appliances. A 12v PV can contribute up to 22v power which is very dangerous for a 12v battery if there is no controller installed with the system. At the same time, power of a full-charged battery can affect the solar panel without a controller. A good quality solar controller control the input current from the PV and output to the battery and appliances exactly what it needs. For example, when a PV gives 17v of power, controller will convert and manage the power to 12v so that the battery or appliances can easily run without getting any kind of shocks. Controller shown in Picture-3 is a good example; however, still the controller is not a good quality product. This type of cheaper controller can’t ensure its efficiency and sustainability.

Picture-4 shows that how the SHS users disconnect the connections from the controller. It also gives the idea on how they manage the wire joints which leads to energy loss.

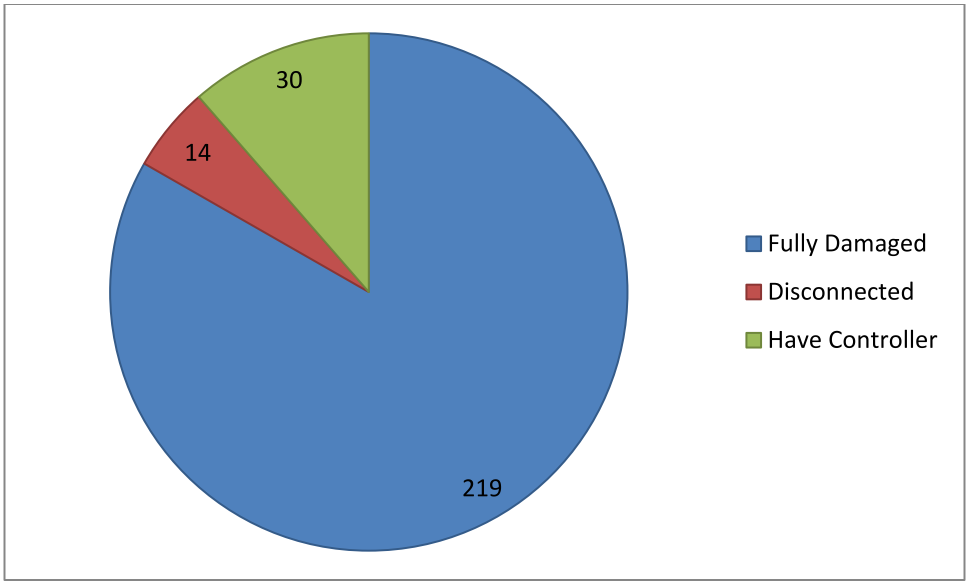


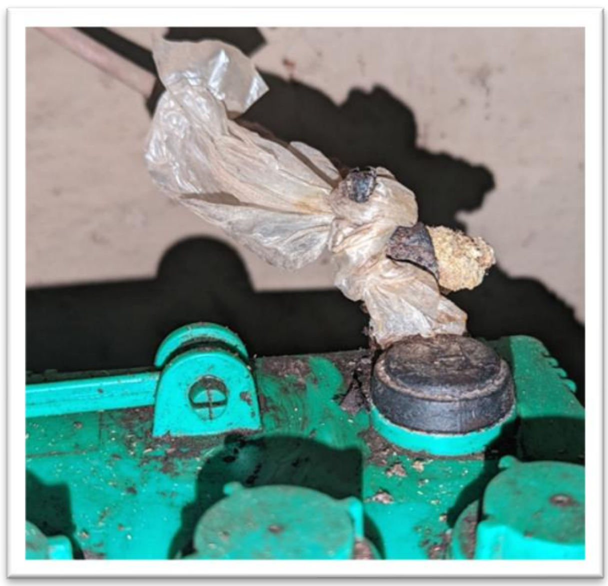
Figure-11: SHSs with and without a controller

Unfortunately, there are many problems found in the study regarding solar controller. Figure-11 shows that only 30 SHSs out of 263are operating along with a controller. Among the rest 233 SHSs are found without controller in which 14 household owners disconnected the controller claiming that the controller is not working properly. Two important role of a solar controller is: firstly, cut-off the power when the battery will be fully charged so that the battery can't be over-charged anymore, and secondly, to secure the DOD of a battery so that the battery life will be long. These two protections are not ensured in 151 SHSs and hence the battery is being damaged soon.

Sometimes, low capacity SHSs can be compromised without a controller as low power can't harm the battery at a high level. But, more than 50wp SHS must have a controller because its high level of volt and ampere can damage the battery soon by overcharging and over discharging. The main reason of not using a controller is each and every controller is found lower quality and low costs, and so damaged soon. Though all the controllers are marked as "approved by IDCOL", most of the controllers are not functioning appropriately.

7.04 Energy Storage System (ESS)

Most of the SHS user's common objection is the low quality and low life span of the battery. In Bangladesh, traditional lead acid battery is used as the ESS while the whole world is running with lithium batteries. Though lead acid battery has many benefits like low costs, easily available, however, it has significant negative sides like health issue and less DOD. Regular maintenance is essential for this type of battery. More surprising thing is that, this traditional lead acid battery is also responsible for energy loss. Because, it takes long time to getting fully charged while lithium batteries can be charged quickly. Hence, lead acid battery needs more energy to be full-charged than a lithium battery. A practical test was conducted over both the batteries in this study to observe how much energy is being lost due to using a traditional battery that is explain in the "practical test" section.



SHS Capacity	HHs	%	Damaged	%	Good	%	Not Good	%	Poor	%
20 Wp	16	6%	3	19%	2	12.5%	2	13%	9	56%
30 Wp	39	15%	7	18%	5	12.8%	15	38%	12	31%
40 Wp	37	14%	3	8%	11	29.7%	11	30%	12	32%
50 Wp	81	31%	4	5%	19	23.5%	32	40%	26	32%
60-65 Wp	53	20%	3	6%	18	34.0%	20	38%	12	23%
75-85 Wp	21	8%	-	0%	10	47.6%	3	14%	8	38%
100 Wp	9	3%	1	11%	3	33.3%	3	33%	2	22%
120-135 Wp	7	3%	-	0%	4	57.1%	3	43%	-	0%
	263	100%	21	8%	72	27%	89	34%	81	31%

Table-8: Working Condition of Battery Backup

Table-8 demonstrates the present condition of the batteries for each of capacity group. There are no damaged batteries in the 75-85wp group and above 100wp group. Also, highest percentage of good battery found in the same group of SHSs. This is because that, people are much careful for a bigger SHS as the investment is higher and energy generation efficiency of bigger PV panels is little bit higher than the smaller PVs. As per figure-12, 31% battery (81 out of 263) found as poor condition which is responsible for huge energy losses. Because, a poor battery can't store enough energy anymore.

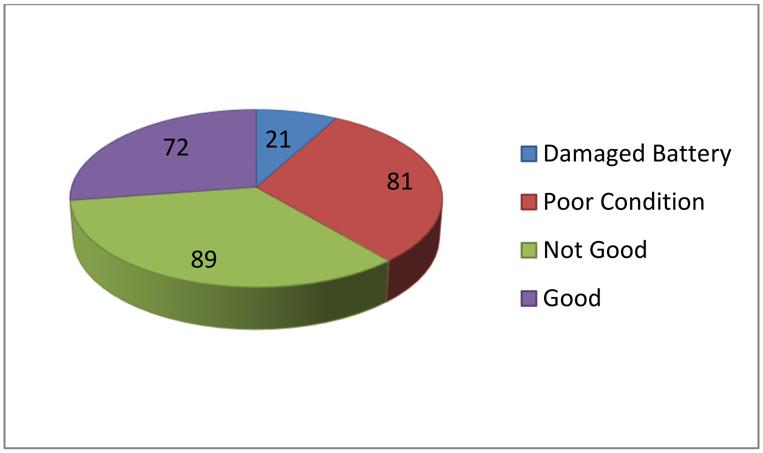
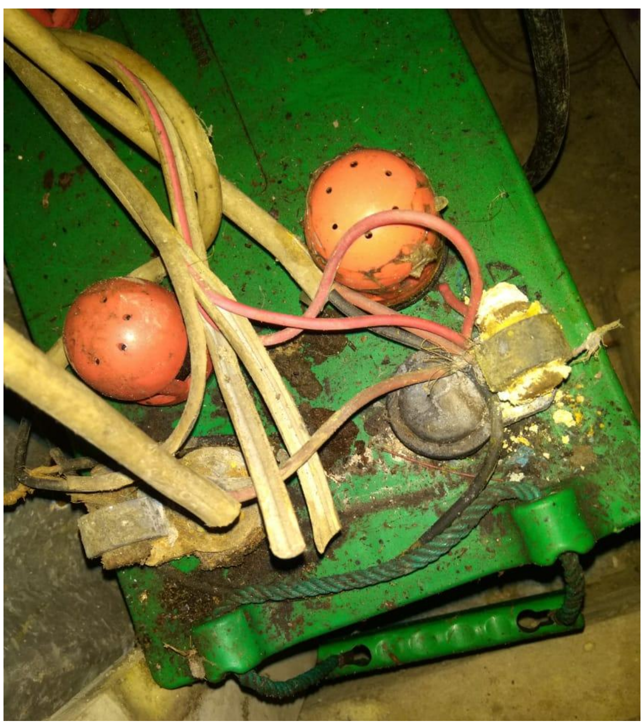


Figure-12: Present working condition of Batteries



Deducting 21 SHSs of which batteries are already damaged, 242 SHSs were analyzed to understand how much energy is being lost from charge-discharge process of the traditional lead acid battery. If we look at the table-9, 16%-30% energy is being lost due to charge-discharge process of the battery. Despite a total of 29522.74 WH energy produced from 263 PVs is stored into the batteries; the users can use only 23394.5WH energy. The reasons behind this 21% of energy loss are: charge-discharge process, poor quality of battery due to lack of water, lack of maintenance, bad connections, and old-aged battery. Most energy loss is found in the 20wp SHSs. Many SHS users are consuming energy for their fans or lights at day time. Otherwise, this percentage of loss would be higher more. A lead acid battery always responsible for some energy losses as its charging procedure is different than the latest batteries such as lithium, however, the losses that found at the study area is not expected at all.

One major reason of the excess loss is, most of the SHSs don't have a appropriate controller. So, the user can't understand whether the battery has sufficient charge or not. A practical test was conducted to understand the comparison between the two types of battery which is explained end of this section.

SHS Capacity	HHs	%	Input Energy (WH	Usage (WH)	Loss (WH)	Loss (%)
20 Wp	13	6%	638	447	191	30%
30 Wp	32	15%	2,359	1,818	542	23%
40 Wp	34	14%	3,016	2,425	591	20%
50 Wp	77	31%	8,420	6,656	1,764	21%
60-65 Wp	50	20%	6,628	5,163	1,465	22%
75-85 Wp	21	8%	3,818	3,065	753	20%
100 Wp	8	3%	2,187	1,746	441	20%
120-135 Wp	7	3%	2,458	2,075	383	16%
	242	100%	29522.74	23394.5	6128.24	21%

Table-9: Energy loss through charge-discharge process.

There is an inconsistency found in selecting appropriate capacity of battery with a specific SHS. Always the PV capacity should be three times higher than the battery so that the battery can be charged fully every day. This charging and discharging process is very important for the battery health. But, most of the cases, the batteries are found much higher than the PV panel. As a result, the battery never gets full charged. For example, among 20wp SHSs, 240wh in one HH, 360wh in four HHs, 480wh in two HHs, 660wh in one HH, and 960wh in one HH was found (see table-10).

			Battery Capacity (WH)												
SHS Capacity	No.	%	240	360	480	600	660	720	960	1200	1320	1440	1560	1800	Damaged
20 Wp	16	6%	1	8	3	-	1	-	1	-	-	-	-	-	3
30 Wp	39	15%	-	24	2	1	2	2	1	-	-	-	-	-	7
40 Wp	37	14%	-	4	11	3	9	4	3	-	-	-	-	-	3
50 Wp	81	31%	-	4	1	8	15	16	27	2	1	1	-	1	4
60-65 Wp	53	20%	-	-	1	1	3	10	23	7	1	2	-	-	3
75-85 Wp	21	8%	-	-	-	-	2	1	10	3	1	-	3	1	-
100 Wp	9	3%	-	-	-	-	-	-	1	6	-	-	1	-	1
120-135 Wp	7	3%	-	-	-	-	-	1	1	-	-	1	4	-	-
	263	100%	1	40	18	13	32	34	67	18	3	4	8	2	21

Table-10: Battery capacity vs PV capacity

According to the field measurement of this study, maximum output capacity of a 20wh PV was found as 71.96 wh per day. So, 5 full sunny days will be needed to charge a 360wh battery fully from a 20wp PV without using any appliances. In that situation an alternative way is to charge the battery from grid electricity atleast once in a month. However, very few users have this knowledge and so they think bigger battery can produce bigger benefits and at the end the battery become weaker due to lack of energy, and then become poor, once it is damaged.

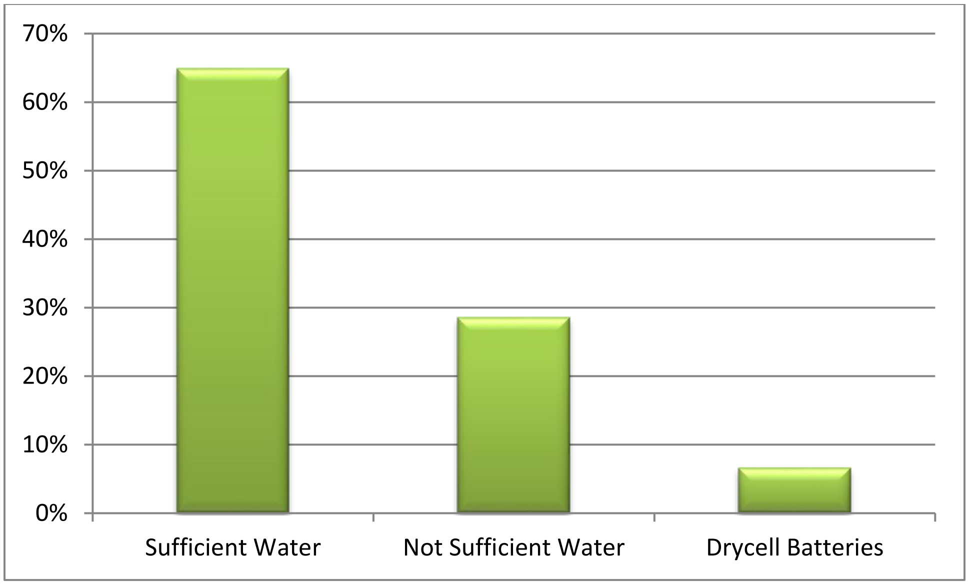


Figure-13: Water level of a flooded battery.

A lead acid battery needs regular maintenance such as giving distilled water into the battery, changing the acids, doing a full-charged through grid electricity, etc. Very few users were found who take the batteries to a workshop at least once in a year for changing the acid and other maintenance. Even more than 60% of users do not clean their batteries regularly. If we look into the table-11, there are only 38% batteries that were found cleaned. Among the 62% of dusty batteries, 27% of batteries were found very poor in cleanliness. Most of the SHS users are aware of giving water into their batteries in a regular basis. Figure-13 presents that, only 29% batteries found which don't have sufficient water in it. 65% batteries have adequate water and 7% batteries don't need water because those are dry battery. Comparatively, dry battery is better than the flooded battery as dry batteries are maintenance free, and low cost. But, life span of this type of batteries is very lower than the flooded battery.

SHS Capacity	No.	Cleanliness			Wiring			Connections		
		Clean	Single Layer Dust	Several Layer Dust	Good	Not Good	Poor	Good	Not Good	Poor
20 Wp	13	3	2	8	2	4	7	3	1	9
30 Wp	32	5	13	13	4	13	15	4	12	16
40 Wp	34	14	11	9	8	17	9	7	20	7
50 Wp	77	26	29	22	16	41	20	18	38	21
60-65 Wp	50	20	21	9	15	25	10	16	25	9
75-85 Wp	21	11	7	3	3	12	6	5	8	8
100 Wp	8	7	1	-	3	5	-	4	4	-
120-135 Wp	7	5	1	1	4	3	-	4	3	-
Total	13	3	2	8	2	4	7	3	1	9
		38%	35%	27%	23%	50%	28%	25%	46%	29%

Table-11: Cleanliness, Wiring and Connections of Batteries.

Wiring and connections are two major parts from where energy can be lost. About 23-25% of SHSs found where the wiring and connections are organized, clean, and in good condition. Out of 75% of bad wiring and connections, 28-29% of batteries were found in very poor conditions.

Most of the users are not much aware on how should take care of a battery, why should keep the battery in a clean and safe place, why wiring joints should be covered, why the connectors should be clean, etc. Many batteries are found where several wire joints are fully opened and placed in cluttered situations.

7.05 Practical Test:

A practical experiment was conducted at holding no-956 under Burigoalini Union. Name of the HH owner is Taposh Kumar Mondol, who is a night guard of Burigoalini Union Parishad Office. This household was selected depending on three major reasons: firstly the owner has two different SHSs in which one 30wp system he has been using for his house and another 40wp SHS is turned off for damaged battery and controller. Secondly, the person has technical knowledge about SHSs and thirdly, the location is very good to communicate regular. 67% of energy loss was found during the survey period due to poor wiring, bad connections and dusty PV panel. All the weaknesses of that system were anticipated before conducting the test work such as repairing the connection faults, cleaning the panel, set up the panel in a right direction etc. A 30ah lithium phosphate battery pack was installed with the 30wp SHS.

System1:
Panel: 40w Mono, Age-8 yrs
Controller: I0A IDCOL approved
Battery: Volvo Lead Acid 30AH (30x12=360WH)

	Date	Weather	Output during 10am to 1pm (W/hour)	Total output energy from PV (WH/day)	Discharged Energy (WH/day)	% of Discharge	Energy Loss (WH/day)	% of Loss
Day-1	2-Nov-23	Full	26.1	169.9	121	71%	48.9	29%
Day-2	3-Nov-23	Full	26.4	170.2	125	73%	45.2	27%
Day-3	4-Nov-23	Full	27.3	171.6	119	69%	52.6	31%
Day-4	5-Nov-23	Full	27.7	172.3	119	69%	53.3	31%
Day-5	6-Nov-23	Full	25.6	166.3	131	79%	35.3	21%
Day-6	7-Nov-23	Full	25.4	167.5	131	78%	36.5	22%
Day-7	8-Nov-23	Full	25.3	167.4	129	77%	38.4	23%
Day-8	9-Nov-23	Full	25.4	168.7	120	71%	48.7	29%
Day-9	10-Nov-23	Full	26.1	170.5	118	69%	52.5	31%
Day-10	11-Nov-23	Full	26.4	171.6	119	69%	52.6	31%
Average per day			26.17	169.60	123.20	73%	46.40	27%

Table-12: Practical Test – Energy Loss from System-1

A new Volvo branded 30ah lead acid flooded battery was installed with another SHS which was turned off. Both the SHSs were trialed for 10 days to observe whether it is working good or not and how much energy loss can be reduced.

Finally, the experiment was conducted from November 2, 2023 to November 11, 2023 for days. Table-12 shows the data how much energy was produced from the PV, how much energy discharged from the battery and the figure of energy loss is occurred. Table-13 shows the same data for the practical test of System-2.

System2:
Panel: 30w Mono, Age-8 yrs
Controller: I0A IDCOL approved
Battery: Prismatic LiFepo4 25AH (30x12=300WH)

	Date	Weather	Output during 10am to 1pm (W/hour)	Total output energy from PV (WH/day)	Discharged Energy (WH/day)	% of Discharge	Energy Loss (WH/day)	% of Loss
Day-1	2-Nov-23	Full	19.6	126.9	116.3	92%	10.6	8%
Day-2	3-Nov-23	Full	19.7	127.7	117.5	92%	10.2	8%
Day-3	4-Nov-23	Full	19.8	126.4	118	93%	8.4	7%
Day-4	5-Nov-23	Full	20	125.8	120.2	96%	5.6	4%
Day-5	6-Nov-23	Full	19.1	125.1	118.5	95%	6.6	5%
Day-6	7-Nov-23	Full	19.3	126.6	119.1	94%	7.5	6%
Day-7	8-Nov-23	Full	19.2	125.4	117.9	94%	7.5	6%
Day-8	9-Nov-23	Full	19.6	127.6	117.3	92%	10.3	8%
Day-9	10-Nov-	Full	19.8	125.3	120.6	96%	4.7	4%
Day-	11-Nov-	Full	19.9	129.2	118.6	92%	10.6	8%
Average per day			19.60	126.60	118.40	94%	8.20	6%

Table-13: Practical Test – Energy Loss from System-2

According to the above data from practical test, following results are realized:

1. PV output can be increased if it is cleaned, well connected with good cables, and installed in right direction with appropriate tilt angle without any shading obstacles. Both the PVs (30wp & 40wp) used in the practical test are 8 years old and were struggling to generate energy. After cleaning and reorganizing the proper installation, maximum output is ensured through the PVs.
2. During the test it was found that the 40wp PV can generate a maximum of 172wh and 30wp PV can generates 129wh energy in a full sunny day which is more than the average output level of Global Solar Atlas (GSA).
3. A maximum of 31% of energy loss is found in terms of the charge-discharge process of Lead Acid Battery installed with the System-1 (40wp SHS). On the other hand, maximum 8% energy is lost due to charge-discharging process of System-2 (30wp SHS). That means, more than 75% energy loss of System-1 can be reduced if a lithium battery is installed instead of a Lead Acid Battery.

7.06 Discussion

According to the findings of this study, averagely more than 58% energy is being lost every day through the SHSs (Table-2), in which more than 65% loss is occurred from smaller capacity SHSs such as 20wp and 30wp and this percentage is comparatively lower for the bigger powered SHSs like 100wp to 165wp. These outcomes indicate high level of ignorance on SHS particularly by the small SHS owners. The study also identified that the overall performance of the SHSs was high before establishing the national grid connection in 2018, which can be a big reason of that ignorance. However, to ensuring energy resilience it is essential to take care of the SHSs because regular load-shedding is very common particularly in the coastal rural areas especially during the hot weather. Moreover, the grid electricity is fully disconnected for 4-5 days after any natural disaster such as cyclone or even during a storm. Despite this hazardous situation of energy security, high level of ignorance on SHSs is unexpected.

Out of 58% of total energy loss, more than 47% loss is responsible for dusty solar panels, bad connections, poor wirings and wrong placement of the panels. More than 80% energy loss is found in some specific SHSs of various capacities for having shading effects; several layer of dusts and spots, and wrong direction and tilt of the PVs. This indicates a huge lack of awareness of the SHS owners as well as not having a minimum technical knowledge. Many wirings is found during the survey where the SHS owner use polythene paper instead of PVC electric insulation tape to cover the joints of cables. Further, several SHSs are found in this study where very poor quality cable is used.

More than 83% of SHSs is found without a charge controller, 11% with a charge controller, and the rest 6% SHS owners disconnected the charge controller by themselves. Most of the SHS owners think that charge controller is not essential rather it create limitation on using full backup of the battery. However, they don't know how the PV cells and the battery can be damaged without a solar charge controller. One more unexpected thing that out of 11% charge controller, most of them is not working properly as the controllers are very low in quality.

Analyzed data demonstrates that out of total energy loss, more than 11% loss is occurred through the energy storage system. The SHS owners have a very good awareness on pouring water into the battery; however, they are not much aware about the cleanliness and regular service of the battery. Many batteries found where the connections are too dusty. 21 SHSs are found with damaged battery and very poor batteries are found in 81 SHSs, where significant loss is found in the study as these batteries are not able to store enough energy anymore. Due to lack of knowledge the SHS owners can't understand why the SHS is not working properly.

7.07 Recommendations:

- The practical test results identified that 47% of energy that is lost for dust, wrong direction, inappropriate tilt angle, and poor wiring and connections can be reduced by 100% through just raising awareness. No cost will be needed for regular cleaning the PVs and reorganize the PVs as per right direction and tilt. Only little money may be required for upgrading cable lines and connections.
- Few Households are found in the survey where a family-member has minimum technical knowledge on how the solar home system works and how to take care of it. SHSs of those households are running comparatively well and in very good condition. So, it would be great idea to train at least one person of each SHS owner on the basic techniques of operating a SHS.
- People are much suffered when they face technical problems of the SHS because there is no service center nearby and a solar technician is rare. It will be a very good idea if the Government could establish SHS service station in every union council. This will not only enhance the sustainability of the existing SHSs, but also can encourage the people to buy new bigger systems.
- A good quality Charge Controller can serve many years. This study demonstrates that all the charge controllers installed with the SHSs are cheaper and low in quality. Though, product quality or brand isn't

considered in this study, however, buying a quality product can ensure its sustainability as well as reduce the energy loss. For example, German branded Solar PV is better than China branded PV.

- The practical test proves that Lead Acid battery is responsible for a huge energy loss as the charge discharge process of this battery is complicated. Lithium battery is very good alternative for the SHSs. But, this type of battery isn't available yet in Bangladesh. The Government should adopt new policies/regulation to promote new battery technologies among the lithium family.
- As Bangladesh has a ambitious target in the NDC on renewable energy generation, a strong and active monitoring cell should be organized to take care of existing solar grids as well as promoting new grids and manage Research & Development on sustainability and resilience.
- Sustainable Renewable Energy Development Agency (SREDA) is playing pivotal role in promoting and establishing Solar Projects in Bangladesh. They should look into the energy loss problems at the rural areas because there are more than 6 million SHSs are installed in Bangladesh. SREDA can monitor and control over the solar companies who produce and market low quality products.
- The Government of Bangladesh has already been introduced Net Metering system for the solar-powered grids which has brought many opportunities to generate energies through community based solar system. Also, this system can reduce 80% of energy losses. But, this system isn't yet user-friendly, isn't easy to access, and this is only for those who have a minimum of 5kw solar system. People would be encouraged if this limitation could be fixed by 500wp.

8. Conclusion

Identifying actual energy loss from SHSs is very much complicated, time consuming, and also costly. This is the first study in Bangladesh where 263 SHSs are surveyed, measured, and analyzed to identify energy loss. Many more factors need to be considered to measure the PV outputs, such as: weather condition, climate etc. Though, all the steps are taken to ensure the accuracy; however, the percentage can be vary location to location, season to season. It would be more reliable if the practical tests and PV measurements could be taken in different seasons. Nevertheless, this study will contribute a significant role on reducing energy loss and create opportunities on further studies. Since, the country still has power crisis and has a high level of target on promoting renewable, it is essential to do more research on energy loss and its reductions which can contribute to ensure sustainability, reduce energy loss, and enhance energy resilience.

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