SMALL SCALE PV INTEGRATION IN BANGLADESH: OPPORTUNITIES, CHALLENGES, AND RECOMMENDATION

by

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CERTIFICATE OF APPROVAL

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DECLARATION

It is hereby declared that this work has been done by us and no portion of the work contained in this thesis/project has been submitted elsewhere for the award of any degree or diploma.

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ABSTRACT

Small scale on site renewable energy generation is getting a common feature of modern energy system in developed countries both in business and residential sectors. Solar home system (SHS) is the most widely used form of such renewable energy source around the world. Residential users, small business, office, industries all are implementing on site PV generation to fulfill the clean energy policies, to increase the resilience of the system as well as better economic options. Since early 2000s Bangladesh govt has started to introduce nano and micro scale to the population who are at the remote corners of the country and where electric grid line wasn't reached. In recent years, Bangladesh has made tremendous improvement in the electricity sector and the demand and generation now match each other. In this situation, those nano scale PV systems doesn't make any economic sense. Moreover hand the existing PV market, policies are not good enough to attract mass population to install small scale PV system known as SHS in private initiative.We have tried to replicate the current SHS policies and pricing along with the obstacles. Our expectation was to see the economic viability of the current system. For this purpose, we have constructed yearly load profile of 3 consumers. Then we used these load profiles to evaluate the economic viability of the current system. After this we have applied different renewable friendly policies, incentives, net metering to find out the economic viability of the modified system. And for testing the economic viability we have chosen REopt tool. Then we have used three hypothetical scenarios to see the effectiveness of these policies and strategies to make SHS attractive to the mass people. We have used residential and small business load profile to simulate in REopt. The outcomes of this work suggests that net metering along with financial policies will make SHS attractive towards mass people.

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LIST OF ABBREVIATIONS

PV	Photo voltaic
SHS	Solar home system
GHG	Green house gas
REopt	Renewable energy optimization
IDCOL	Infrastructure Development Company Limited
RERED	Rural Electrification and Renewable Energy Development
GEF	Global Environment Facility
BPDB	Bangladesh Power Development Board

CHAPTER 1
INTRODUCTION

1.1 Introduction

Extended usage of fossil fuels for the last two centuries brings some extreme challenge towards us. Some of the most dangerous ones are rise of global temperature up to 3°C, huge amount melt down of arctic ice, flood of coastal areas because of the sea level increase, very unpredictable behavior of nature and natural calamities and many more [7]–[10]. Awareness towards environment concerns has risen at a very good level among mass people around the world although policy makers are not seen extremely concerned about this fact yet. However the govts around the world are also seen noticeably positive towards renewable ever before. Because of this, renewable energy sources are getting a significant boost in global electricity generation share each year compared to the previous year [11].

1.2 Background

Among the many renewable energy sources solar pv, wind turbines and biofuels are the most prominent ones. Beside large scale integration of renewable energy sources into the existing grid micro and nano scale integration of renewable sources are also gaining popularity around the world. Micro and nano scale integration of these renewable sources are primarily integrated by the general consumers of electricity. Solar home system (SHS) is such a nano scale renewable energy source installed in the rooftop or at free land by private owners. SHS has seen a significant boost over the last decade both in developing and developed countries [12]. Developing countries like Bangladesh has also been greatly benefited from SHS especially through solar lighting and providing electricity for basic connectivity like charging phone, running radio-tv etc. Nano scale SHS also played a significant role in providing electricity to the furthest and most remote corners wheres grid connectivity was not available [13]. In the early 2010s the socio-economic benefits of this nano solar program basically run by IDCOL(Infrastructure Development Company Limited) was huge [14]. These nano renewable sources fulfill lighting, connectivity and entertainment to the consumer. Cost to benefit ratio to these users were very high because these small source of energy played important role in changing their life. But these small scale SHS are not making any economical and energy sense with the changed perspective of the nation. In the next section we will discuss the IDCOL(Infrastructure Development Company Limited) solar program in details.

1.3 The Problem of IDCOL SHS Program with the Changed Perspective

The term IDCOL refers to Infrastructure Development Company Limited that is a govt. owned organization focused to promote renewable energy sector in Bangladesh. IDCOL basically promoted very small scale SHS ranging from 20 W_p to 130 W_p with a price tag of 140 USD to 940 USD to the consumers. Consumers need to pay this money in small installments within a given period of time [14]. Up until 2012 IDCOL has installed more than 1.6 millions of nano SHS where electricity was not available. IDCOL SHS program has started to get shadowed when the country started providing massive new electric connection to every corner of the country [15]. In this new circumstances IDCOL electrification program does not carry any economical sense because of the extremely high price tag of the system.

→ IDCOLs 130 W_p system costs 940 USD which makes a 1000 W_p system costs around 7000 USD.

→ Beside this unreal price tag the socio economic benefits of installing SHS has also been shadowed.

These two factors made this conventional method of installing nano SHS not viable with the changed perspective.

1.4 Current SHS Installing Markets in Bangladesh

We have discussed SHS in detail in chapter 2. Here the current status of SHS market in Bangladesh will be discussed. Currently very few SHS are being installed in private initiative compared to rest of the world because of various issues as per such as

- lack of consciousness, knowledge and skills
- less involvement of important stakeholders in this field
- market and financial mechanisms
- lack of renewable energy friendly policies and so on [16].

If we break these key points we get a whole scenario. Market and financial mechanisms as well as policies plays a very key role to make mass population interested towards SHS.An overview of the current scenario of the PV system based on market analysis has been shown in **Table 1.1**. Currently, a low quality panel based 1kW on grid system costs around 1200 USD to 1600 USD while off grid system. The life cycle performance of these low quality pv cells are not beyond question.

Table 1.1 Overview of PV system based on market analysis

Parameters	**On-grid PV**	**Off-grid PV**
Cost	1000 to 1600 USD	2000 to 3500 USD
Life cycle	15 to 25 years	pv - 15 to 25 years battery - around 3 years
O & M	20 USD	100 USD
Power Quality	decent	bad
Replacement	15 years at least	battery need to change within every 2/3 years
Payback time	might be around 20 years	hardly paid off

1.5 Problem Statement

We can summarize the key problems towards installing SHS through private initiatives as following:

1. High capital cost
2. Unreliable and low efficiency system
3. High operation & maintenance cost in case of off grid systems
4. Very short life cycle duration of batteries
5. Very lengthy payback years in some cases these systems are not even profitable with a long life cycle time.
6. Lack of environment concerns

Overall, because of these problems pv systems couldn't gain popularity and necessary trust among mass population. Govt policies and lack of incentives as well as good financial models are also big hindrance towards SHS.

Lack of proper knowledge and skills can also be considered as a big problem in this regard. Environment concerns will never make the people of this country move towards

SHS because of not understanding the hazards of environment crisis well. Financially beneficial model can do this job. If SHS becomes financially profitable, payback years become less lengthier , capital cost becomes lower as well as good financial mechanism of paying in installment then SHS will become popular and trustworthy among mass energy consumers. **What do we can do in this circumstances?**

1.6 Motivation of this Work

These obstacles towards installing SHS are the primary motivations of this work. We have tried to replicate the current SHS policies and pricing along with the obstacles. Our expectation was to see the economic viability of the current system. For this purpose, we have constructed yearly load profile of 3 consumers. Then we used these load profiles to evaluate the economic viability of the current system. After this we have applied different renewable friendly policies, incentives, net metering to find out the economic viability of the modified system. And for testing the economic viability we have chosen REopt tool.

1.7 Objectives

The main objectives of this work is as below-

- To identify the current state of SHS in the world, especially developed and developing countries and comparing the situation of Bangladesh in this regard.
- To make load profiles of the specific consumers and identify the scenarios for REopt simulation
- To analyse the results of REopt simulation
- To find out the problems of the current situation of SHS in Bangladesh and to recommend solutions based on the result of this study.

1.8 Purpose of Using REopt Lite

There are many tools to simulate, analyze and test solar PV system such as MATLAB Simulink, PVsyst, HOMER, RETScreen, System Advisor Model (SAM), DER-CAM, EnergyPro, TRNSYS, eSyst and so on. But the unique features of REopt is -

- It can suggest the most optimized operation strategy with a combination of the chosen technologies in the following perspective
  - economical
  - environment friendly
  - resilient

- Not much technical knowledge is required to use REopt web tool although it is recommended to consider careful selection of the inputs.
- Since all the the code and working methodology of REopt is open source there's no black magic is going on behind the simulation.

1.9 Thesis layout

This thesis paper has been organized in the following order-

- This **First Chapter (Introduction)** provides a background, motivation and overview of this work.
- **Chapter two (Literature Review)** presents literature review about the overview of SHS worldwide.
- Simulation and data collection that means load profile creation methodologies are presented in **Chapter three (Methodology)**.
- **Chapter four(Renewable Optimization in REopt Lite Web Tool)** provides information about the REopt simulation
- Result and analysis of this study is given in **Chapter five (Result and Analysis)** .
- Concluding remarks, limitation and future scopes of this study is presented in **Chapter six(Conclusion)**.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

A solar home system consists of a photovol- taic solar panel, a storage battery, a battery charging controller, and various pieces of end-use equipment like florescent lamps. Solar home systems can eliminate or reduce the need for candles, kerosene, liquid propane gas (LPG), and/or battery charging. We can see a basic model of a Solar Home System in **Fig. 2.1** . Direct economic benefits include avoiding the costs of battery charging and LPG or kerosene purchases; other significant benefits include increased con- venience and safety, improved indoor air quality, a higher quality of light than kero- sene lamps for reading, and reduced CO2 emissions [2], [17].

A solar home system may be a possible alternative supply of electrical energy. This method is changing into tremendously popular and is taken into account as a response to the energy drawback within any countrys rural areas [18].

Fig. 2.1 A basic model of a SHS [17]

Solar home system (SHS) is therefore technically applicable and cost-efective means for electricity generation for remote households not served by the national electricity grid or areas which are not densely populated to favor a local minigrid. According to the latest

Off-grid Renewable Energy Solutions brief from the International Renewable Energy Agency (IRENA) from July 2018 , 100 million people were using solar lights (greater then 11 Wp) and 24 million were using solar home systems - SHS (>11 Wp) in 2016. Solar home systems are small stand -alone systems suitable for households for a variety of appliences, such as lighting, TVs, fridges, mobile phone chargers, etc. They are low power, up to 150 Wp, and are usually composed by photovoltaic (PV) modules, a charge controller and a battery system, plus an inverter if the appliances are AC powered. As 133 million people had access to lighting and other electrical services using off-grid renewable solutions, solar constitutes an important share of the off-grid renewable energy [19].

Fig. 2.2 A Rooftop Solar Home System [18]

The installation of SHSs are motivated by different objectives, typically the electrification of remote rural areas the economic gains (self-consumption and feed-in remuneration) in grid connected installations . In **Fig. 2.2** we can see a rooftop solar home system installed in a building. Besides the economic viability of such installations, the increasing concerns about the environmental problems dealing with the traditional power systems, fueled by fossil fuels, has brought environmental sustainability analyses to be as important as the economic ones [17]. In several countries, World Bank (WB) loans toward SHSs program exist. Loan schemes are also in operation in some countries. Bilateral donors have succeeded in funding large-scale deployment; a typical example is AusAId project in Indonesia where 36,000 SHSs were funded by Australian government. Nevertheless, in most cases, there is a supply push to assist the local industry of the donor country. Export subsidies assist in creating large market base and reduce SHS costs; hence, it can help in reaching a quantitative target especially the majority rural poor, but sustainability aspects after the end of the project remains appalling. A major barrier facing many poor rural consumers is that they are compelled to spend a considerable amount of their limited income on low-quality, expensive energy sources, such as candles and kerosene, since they cannot aford cleaner energy alternatives such as SHS [17], [18].

A basic solar home system consists of a small solar panel, a battery, and a charge controller as shown in **Fig. 2.3**. Every solar system collects energy from the sun. A solar system does not create the energy, but instead converts energy from the sun into electricity our home can use.solar panels are what absorb the sun's energy and convert it into electricity.

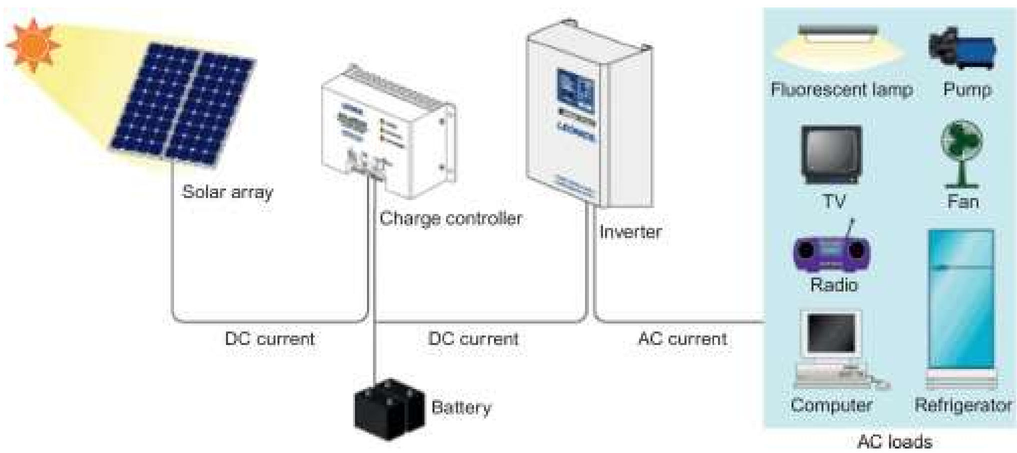


Fig. 2.3 Basic components of a Solar Home System [2]

The panels are made of silicon, a semi-conductive element that generates DC (direct current) electricity when sunlight touches it. The amount of electricity a panel can generate depends on many factors, including but not limited to, the type of panel, placement of panel, time of day, and temperature. The best way to determine the amount of energy a panel can produce is by looking at the efficiency rating. Efficiency is defined as the amount of power produced by the panel per square meter (m2) of sunlight at Standard Testing Conditions (STC). Basically, the more efficient a solar panel is the greater potential for more energy production in a given footprint. The average efficiency of solar panels falls between the 17 to 19percentage efficiency range. The electricity that is generated from your solar panels is DC electricity. However, the grid, and appliances in our home, run on AC (Alternating Current) electricity. Simply the inverter takes the DC electricity collected from our panels, and converts it into AC electricity so you can power our home.The system costs approximately 350dollars, which can be sourced from a financial institution (preferably a microfinance bank) at a modest rate [18]. Through discussions with local banks and microfinance companies, convenient payment plans can be negotiated, which would ultimately help to finance the large initial investment cost involved in purchasing the new system [18]. For different household appliances and lighting purpose, by 2017 a total number of 5.2 million Solar Home Systems (SHSs) with a capacity of 218 MW, were installed. The total capacity of the installed SHSs was 218 MW. This information was published in Renewables 2018-Global Status Report, which is released annually by the Paris-based energy think-tank REN21 in June [18], [2].

Solar home system project designs have continuously evolved with increased understanding of best practices. In general, projects are designed to overcome barriers to the widespread and accelerated dissemination of solar home systems in a given country context, such as:

- Lack of an established market;
- Lack of successful business models & finance skills;
- Unwillingness of utilities to provide off-grid electricity services;
- High transactions costs;
- High first cost and affordability;
- Lack of consumer financing;
- Uncertain technological track record;
- Uncertain or unrealistic grid expansion plans; and
- Other policy constraints like subsidies, tariff structures, and import duties [2].

2.2 SHS in Developed and Developing Countries

The energy generation paradigm is shifting from centralized fossil-fuel based generation to distributed -based renewable generation not only in developed countries but also in developing countries. Thus, Solar home systems (SHSs) along with other hybrid residential energy systems are gaining more and more terrain. Nevertheless, such a system needs to be coupled with an energy storage solution, most often a battery, in order to mitigate its power generation variability and to ensure a stable and reliable operation [20].

2.2.1 Scenerio in Developed Countries

The recent development and marketing of new solar home systems, combined with significant price reductions, have been seen by many as a catalyst for a solar energy revolution and have created high expectations in the sector in developed countries. Significant uptake of combined photovoltaic (PV)/battery units is now seen as a possible future, which would lead to increased decentralised generation and higher self-consumption levels. In addition, if current cost reduction trends persist, it is predicted that these systems could ultimately disconnect from the grid and lead to autonomous Solar home system or microgrids. Large-scale solar home systems are a cost-efficient technology to provide renewable heat. The rapid market growth of SHSs in the last decade has been concentrated on a small number of developed countries, with the outstanding position of Denmark followed by China, Germany,Vietnam,Indonesia Austria,Japan,Korea and UAE [3], [21].

About 50% of the total final energy consumption in the world attributes to heat used in the residential and industrial sectors. Space heating and domestic hot water can reach up to 80percentage of the final energy consumption in the residential sectors of EU countries. 84percentage of the heating and cooling energy consumption in the EU is still based on fossil fuels while only 16% is provided by the renewable energy sector . To reach the climate and energy goals of the Paris agreement and international and national energy policies, decarbonization and energy efficiency increases cannot be limited to the electricity sector. The transformation of the heat sector must also be accelerated. That's why the EU countries are also planning to adopt SHSs. Infact they already began to approach the method [21]. At present, however, solar home systems are not in themselves economically viable in most EU countries: rooftop PV panels still require subsidies in the form of feed-in-tariffs, green certificates or favourable net metering schemes. The benefits of

Fig. 2.4 A SHS in Germany [3]

battery systems are closely linked to higher levels of selfconsumption and thus to exemptions from taxes and grid fees on the self-consumed part [3].

Among the developed countries Denmark, China, Vietnam are the largest cunsumer of SHSs. We can see a solar home system in **Fig. 2.4** installed at Germany. These countries are adopting SHSs to fulfill their daily basic electricity needs. Specially in the rural areas of Denmark, China, Vietnam fully depends on SHSs. Some remote areas of the states of USA highly depends on SHSs. Most of the time this developed countries installs SHSs for residential and small industrial sectors [21].

Although the installed capacity in large-scale systems is still relatively small with less than 1percentage of the total installed capacity of small-scale solar home systems, it is quickly rising in importance. The market has been experiencing rapid growth recently, with an average 15.5 % increase per year in the main markets of Denmark, China, Germany and Austria between 2010 and 2018 [21], [3]. The solar PV total installed capacity in Denmark has exponentially increased in the last years. According to International Renewable Energy Agency(IREA), the cumulative solar capacity raised to 399MW in 2010,and further reached to 790.4MW by the end of 2016. The dominating installations (almost near to 90%) are represented by residential rooftop Solar home system with power levels below 6kW, This trend is expected to continue as by 2020 the aim is to generate 5 percentage of electricity from residential solar home systems [22].

The driving force for large-scale solar home systems has been applications in Denmark, where by the end of 2018 a total of 118 plants with a capacity of 970 MW were in operation, making up 63% of capacity worldwide. Denmark is followed by China (212 MW, 55 systems). China could become the leading market driver and surpassed Denmark regarding newly installed capacity in 2017 and 2018 for the first time. Market data for China might substantially underestimate the total and newly installed capacity. Germany (45 MW, 27 systems) and Austria (27 MW, 23 systems) successfully established niche markets for large-scale solar home systems, ranking number three and four if the two big solar process heat plants in Oman (104 MW) and Chile (28 MW), which were singular installations and not part of a broader market development in Oman and Chile respectively, are not considered. Besides these four countries and Oman and Chile, only Saudi Arabia and Sweden reach more than 20 MW total installed capacity in large-scale solar home systems. Denmark, China, Germany and Austria are the leading countries in SHSs usage with a combined market share of 81percentage in the world [21], [22].

2.2.2 Scenerio in Developing Countries

Power is one of the key requirements for the development of economies and upgrading of standards of living of developing countries.Energy poverty is the lack of access to modern energy services, such as electric power. Energy poverty in developing regions is a major concern on the global level. The International Energy Agency (IEA) estimates that there are currently 1.2 billion people (or roughly 22percentage of the world's population) around the world, most of whom lived in remote areas, still do not have access to the regular electricity around the world who are deprived of electricity, while many more suffer from supply that is of poor quality. [4] The most affected regions are the rural areas of South Asia, South-East Asia and Sub-Saharan Africa. All these countries have strong population growth and accordingly growing need for energy. Basic energy needs, such as cooking and lighting, are covered using traditional biomass and fossil fuels. These are consumed inefficiently in fire stoves and flame lamps. This situation hampers economic growth and social development and implies severe stress on resources and the environment. **Fig. 2.5** shows the population without access to electricity in different regions of the world. Energy poverty is one of the serious issues that world is facing today as it poses threats to economies, national security, the environment, and public health throughout the world [4], [5].

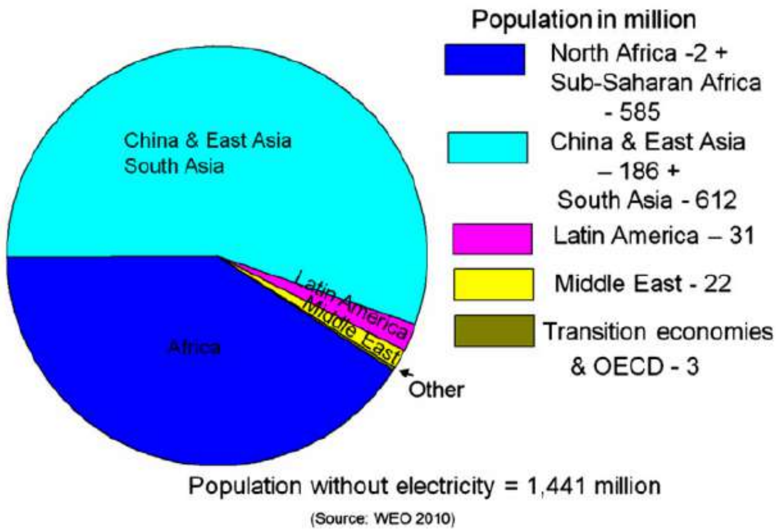


Fig. 2.5 Population without access to electricity in different regions of the world [4].

Generally, for the last two decades, solar power has been the fastest growing source of energy worldwide . The need for cleaner energy sources and exigencies to conserve nature has seen people adopt solar energy. Basic energy and lighting needs in developing countries are satisfed by the following: kerosene, frewood, solar energy, especially solar home systems (SHSs), and use of generators that have limited electricity output and high maintenance cost. SHSs got attraction of the developing countries in late 90s and got accelerated after 2000s [5]. The initial SHS case study results in Sukatani in Indonesia, Sri Lanka, the Dominican Republic, and the Philippines had yielded the key elements into popularization of SHSs in developing countries and for surprising success stories. After these success stories, the World Bank understood that that SHS technology was maturing and commercial markets were developing. In the 1990s, the World Bank began promoting PV systems or SHSs, as a low-cost alternative to grid extension to deliver energy for development to households in Africa, Asia, and Latin America and the other developing countries. By 1999, the Bank, assisted by grants from the Global Environment Facility (GEF), had invested in several renewable energy projects [23].

The popularity of SHSs prompted the World Bank to supply soft loans beginning in 2003 to non-government organizations (NGOs) or microfinance organizations that invest in SHSs. In recent years, World Bank provided US 117.10 million dollars to Yemen to increase access to electricity of rural households in off-grid areas through implementation of SHSs in the Republic of Yemen (May 2009), 50.00 million $ to Argentine Republic for the Renewable Energy in the Rural Market Project including 15,500 SHSs (November 2008), US4.35 million $ to Ghana for the Solar PV System to increase access to electricity services project via solar photovoltaic systems to poor rural households in remote regions of Ghana (October 2008), 160.00 million $ to establish a sustainable program for expanding access to electricity in rural communities and to support the broad-based economic development and help alleviate poverty in Ethiopia (July 2007). The World Bank Group provided loans for the energy sector totaling 13 billion $ during 2010 in mobilizing resources for the promotion of new and renewable energy [16]. Recently, World Bank approves 172 million $ for installing 630,000 SHSs in rural Bangladesh to provide the additional financing to the ongoing Rural Electrification and Renewable Energy Development Project (RERED). Very recently, World Bank has provided US5.52 million dollars to Rural and Renewable Energy Agency of Government of Liberia for lighting lives in Liberia. The World Bank estimates that more than 2.5 million SHSs are installed worldwide and over 850,000 units are installed in Africa. In recent years most of the global growth in SHS sales has concentrated on a few Asian countries and the market potential is expanding to African and other countries also [5], [23].

Fig. 2.6 A SHS in a rural area of India [5]

Solar home systems proposed and adopted in the developing countries like South Asian countries, Sub Saharan countries, African countries are getting more diverse. In **Fig. 2.6** we can see that a SHS is installed in a rural area of India. Like this a lot of developing countries fulfill their electricity needs by SHS. Basically SHS that are typically used in developing countries remain in the range of 1090 Wp, as well as larger systems (generally between 90 and 250 Wp) which can be used by better off families or health centers.

This size is far below the systems of 12 Kilowatts-peak (kWp), which can be found powering houses in industrial countries. In the Global South, a small power supply can help charge batteries, charge mobile phones, produce quality light, power a radio/TV, or power a fan. Less commonly, SHS can be found to power a computer, a (small) fridge, or a (small) pump. Most SHS can be found in rural areas, although they can also now be found commonly in urban settlements, either as main source of power or as a backup. Inspite of so many positive vibes the developing countries still lagging behind in the sector of SHSs.It's Due to the high initial costs of photovoltaic panels,less durability and high initial setup cost. Nevertheless when solar home systems can provide energy access for remote communities at a cheaper cost than alternative sources, they shall be considered systematically as part of the energy mix [4].

2.3 Previous Case Study of SHSs in Bangladesh

Bangladesh is one of the densely populated countries in the world, with 181.4 million people. The power sectors task is becoming more challenging to provide electricity to this vast population and advance towards becoming a digital Bangladesh. Therefore, the Government of Bangladesh (GOB) gives more attention to the development of power sector of Bangladesh and initiates Vision 2021 to provide electricity door to door [24]. Fossil fuels such as natural gas, furnace oil, diesel, and coal are the work-horse for generating power in Bangladesh. However, the continuous decline of natural gas (the most contributing fuel) forces the power sectors authority to look for other sources.The renewable energy sources (RESs), therefore, play a crucial role in addressing the issues. Among the RESs, the generating capacity of only existing hydroelectric generator is not increased, so its contribution to the power sector decreases. In this unfavourable condition, the solar PV system emerges as a promising solution to meet the increasing energy demand, and its contribution increases slowly and steadily year by year [25].

As there is high transmission and distribution cost and also limited generation capacity of electricity, a large number of rural settlements are kept disconnected to the grid as they do not meet the load demand criteria. It is expected that many remote households will remain unconnected to conventional electricity generation and distribution networks in the foreseeable future. The consequence is that a vast majority of rural settlements depend on kerosene lamps for lighting. The high oil price worldwide is causing price rises in kerosene in Bangladesh as well. Thereis also a growing concern about fire hazards and indoor air pollution due to the use of kerosene lamps or wicks (Obeng et al., 2008). Solar home systems (SHSs) provide alternative electricity from sunlight to light rural households where there is little hope for grid electricity supply. As of February 14, 2008, a total of 500,000 SHSs had been installed in all 64 districts in Bangladesh [24].

The SHS program has been very successful in Bangladesh, where SHS projects are managed by a government financial institution (Infrastructure Development Company Limited (IDCOL)). The Bangladeshi SHS model could be replicated and launched in other parts of the world. socio-economic condition, and awareness) have been changed. However,over the years,the basic conditions of SHS technology like package price ,load demands, socio economic conditions and awareness have been changed.

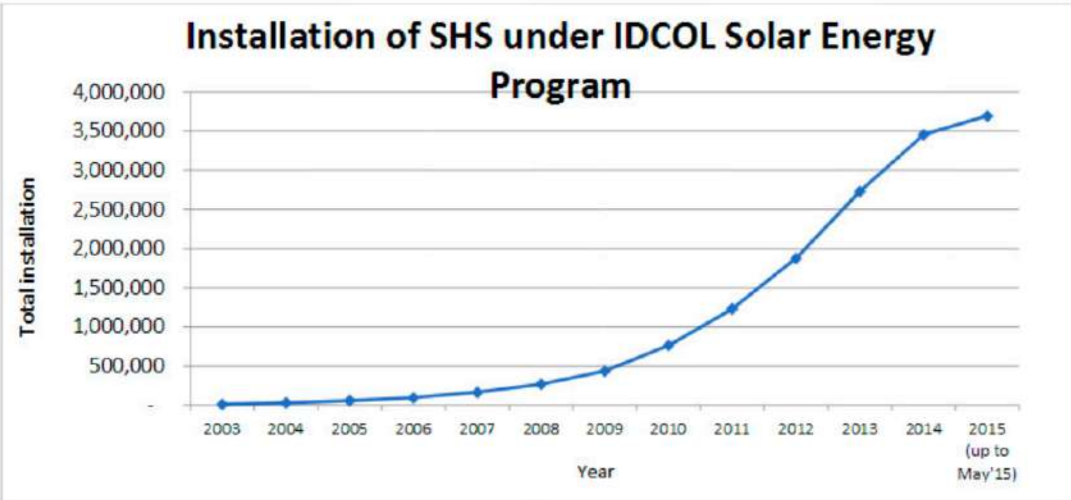


Fig. 2.7 Annual SHS installations in Bangladesh [6]

However in Bangladesh, PV technology is widely used in SHS for off-grid rural electrification with no connection with electrical grid. Major portion of the population in the country are poor and live in rural isolated areas. Only few of them have access to grid electricity due to inadequate generation compared to demand and poor infrastructure. Solar home systems are the effective way to supply uninterrupted electricity to these off-grid areas.In Bangladesh, SHS dissemination was started in 1993 by Rural Electrification Board (REB) though, Rahimafrooz Renewable Energy Limited launched solar PV project in 1985 whereas in China it was started in 1958 [24] . It has been estimated that around 65,000 SHSs are installed per month throughout the country. Till now, approximately 3,863,964 SHSs have been installed as shown in Fig. 7 shows the number of SHSs installed by different government and non-government organizations.By 2021, IDCOL has a target to install about 6 million SHSs to achieve a generation capacity of about 220 MW from SHS [26].

2.3.1 Benefits and Issues of SHSs: Bangladesh Perspective

Paybacks from solar home systems installation Kerosene is the major source of energy used in lighting purpose in un-electrified rural villages. The replacement of kerosene by SHS plays a pivotal role for socio-economic development as well as environmental sustainability. In the subsequent sections, different socio-economic and environmental benefits are described briefly [27].

1. Employment opportunity: electricity plays an important role to reduce unemployment and poverty that are required for attaining the Millennium Development Goals in Bangladesh. The adoption of SHS in households lighting extends working hours in the evening which provides more time to do productive works to increase the household income

2. Improvement of quality of life of rural people: the rural poor people in Bangladesh led very ordinary life. SHS provides good light instead of kerosene lamps and candles which enhance the facility to achieve primary education and provide communication facilities like internet, Skype etc. Therefore, SHS improve the quality of life in rural areas by providing adequate facilities [28].

3. Improvement of environmental sustainability: Environmental sustainability and global worming are the present major concern of the environmental scientists. Kerosene produces indoor air pollution, soot and noxious odors whereas electric light provides approximately 100 times more light than kerosene without any environmental adverse effect. The adoption of SHS in household reduces significant amount of fossil fuels such as kerosene consumption (average 2 l per month per household) .

4. Reduction in distribution and transmission cost of electricity: Bangladesh has more than 87,319 villages and most of them have no grid electricity access. However, the expansion of grid connection is very expensive due to the location and infrastructure of power stations. On the contrary, stand-alone off grid SHS is more effective and viable option for rural electrification compared to grid expansion to those areas as there is no distribution and transmission lines losses. [26]

It is manifest that Bangladesh has already initiated promotion of SHS like many other countries in the South Asian region. Although, the country has a good potential of SHS promotion, the progress is not going on in expected way due to some obstacles sectors as presented below:

1. Policy and regulatory barrier: The lack of clear, long-term and consistent policy, programs and goals is the major barrier for the progress of SHS in Bangladesh though a draft policy has been prepared. There was no recognition of importance of solar energy in the draft national energy policy of 2004 and 2006 [29]

2. Financial barrier: the high installation cost of SHS is another barrier in Bangladesh. It is not affordable to the poor people of the country to install SHS without any subsidy though GS has started to disseminate by soft credit through installments. Furthermore, the high cost of SHS results in lower lifecycle.

3. Technical barrier: there is a lack of standards, quality control and a weak technical link in the system. In addition, local manufacturing and assembly of SHS components and equipment are currently limited due to the lack of technical infrastructure to support.

4. Human resource: limited expertize on system design, installation, operation and maintenance hinders the dissemination of SHS technology in Bangladesh. However, GS has started training program not only for the employee but also for user [29], [26].

5. Lack of Information: lack of information among the public and policy makers regarding technical, economic information about SHS is another barrier for progress of SHS. Another obstacle is that, lack of public awareness and acceptance of solar PV. [26]

SHS can satisfy basic energy needs (i.e., lighting), especially in off-grid rural areas in Bangladesh. SHS has profound and far-reaching economic, socio-cultural, and demographic impacts on life and living of the rural people in Bangladesh. Most of the respondents are found satisfied with their SHS. However, cheaper SHSs and reduced down-payment options combined with more flexible microloan facilities should be introduced to attract poorer target groups to SHSs.

CHAPTER 3

METHODOLOGY

3.1 Introduction

For this work we observed the variation in the electricity usage behavior of a house for couple of days. We noted down the quantity of the loads,power rating of those loads and average summer runtime. In REopt lite web tool we have to use a 24 hour load profile of a house for a whole year. The custom load profile must have 8760 hours of load data for a complete year containing all the variations in the load profile as per the different seasons.

3.2 Making Yearly Load Profile for REopt Simulation

To make such a load profile we have followed the procedure of making realistic load profiles using excel and MATLAB Simulink from a recent paper [30]. The load list of the house is given in **Table 3.1** as shown below:

Table 3.1 Load list of the house

Name	Quantity	Power rating (Watt)	Avergae summer Runtime (hour)	Avergae winter Runtime (hour)
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**			

The following steps has been followed -

1. At first we have made an excel spreadsheet of all the loads of the targeted house with their respective watt rating in watts.
2. Then we have to note down the on off time of each load for a maximum of five times a day.
3. After taking all the loads an initial calculation regarding the amount of total peak loads, total runtime of all loads as well as individual loads can be done based on

the spreadsheet about the load profile of that specific house. The calculations has been performed in the following manner.

$$Runtime_i = off\ time_i - on\ time_i \tag{3.1}$$

$$Total\ Runtime = \sum_{i=1}^{i=5} Runtime_i \tag{3.2}$$

$$Power\ usage_n = \frac{Power\ rating \times Total\ Runtime}{1000} \tag{3.3}$$

$$Total\ Power\ usage = \sum_{n=1}^{n=38} Power\ usage_n \tag{3.4}$$

4. After this based on this spreadsheet, a Simulink model has been created to generate the load profile in real time.

The Simulink implementation of the house is given in **Fig. 3.1** . Here we have an AC voltage source that supplies power to the home. The voltage source is not a constant voltage source. It's value varies around 210 to 230 V which demonstrate an actual scenario of our existing power system. Then we have some common measurement blocks those acts as an electric meter to measure the voltage, current and power of the house. The

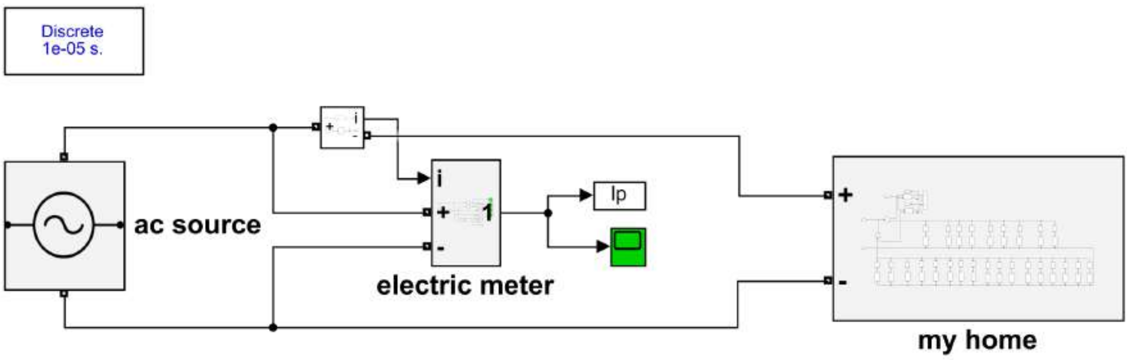


Fig. 3.1 House model in Simulink

detailed about the loads of this house is shown in **Fig. 3.2** . This primary purpose of this house simulation in SImulink is to create two distinguishable real time load profile for this house for summer and winter season.

3.2.1 24 Hour Load Profile Simulation Results

AC voltage source block is shown in **Fig. 3.3** . We have taken a controlled voltage source and then we have applied some random sequence with a constant voltage value. With this method we got the constant voltage to variable voltage as shown in **Fig. 3.4** .

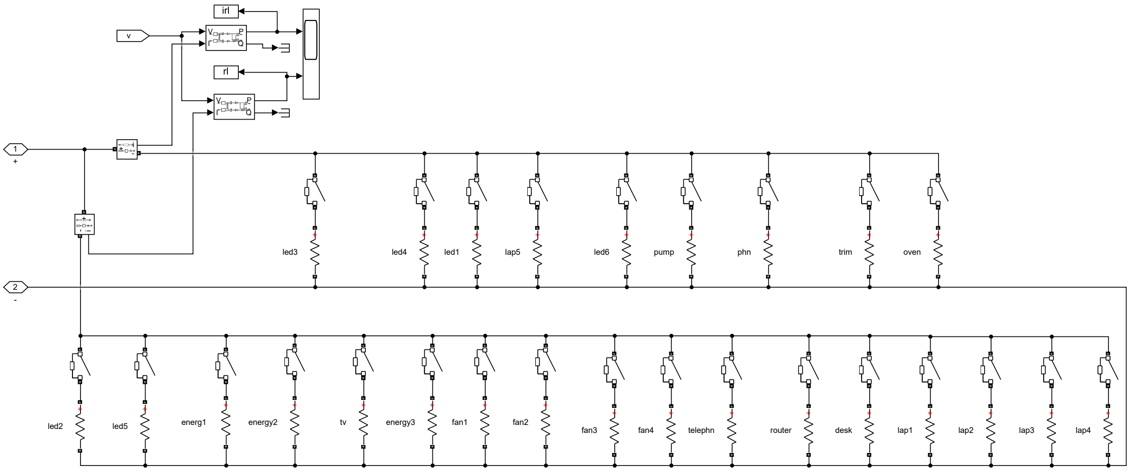


Fig. 3.2 Different loads of the house

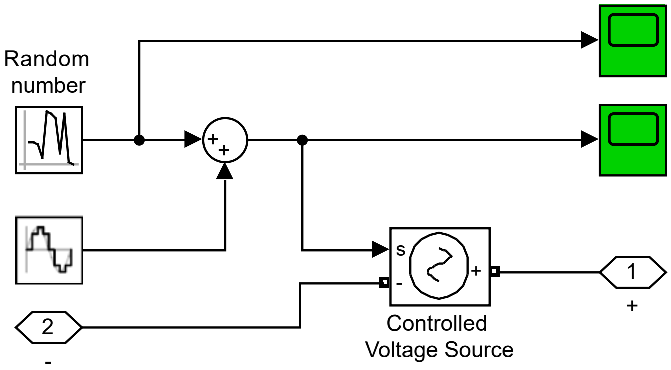


Fig. 3.3 Variable voltage source design

Finally, we have simulated the system considering both summer and winter load in

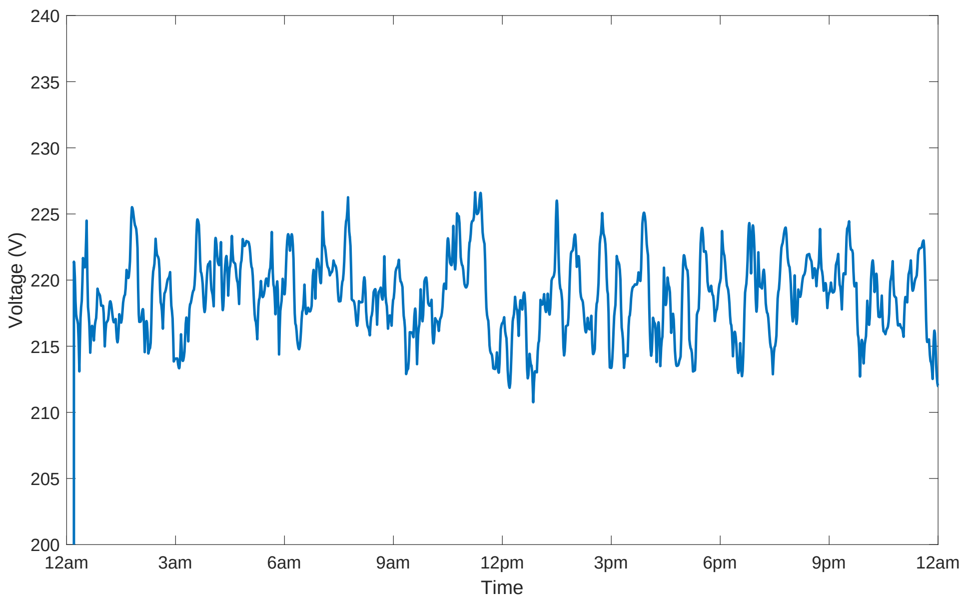


Fig. 3.4 Output of the variable ac source in RMS

mind. The load profiles for both summer and winter is shown in **Fig. 3.5**. The winter load profile has been modified for a representing a realistic scenario. The code is given in section 7.1. For working with REopt we have to make a 24 hour version of this load

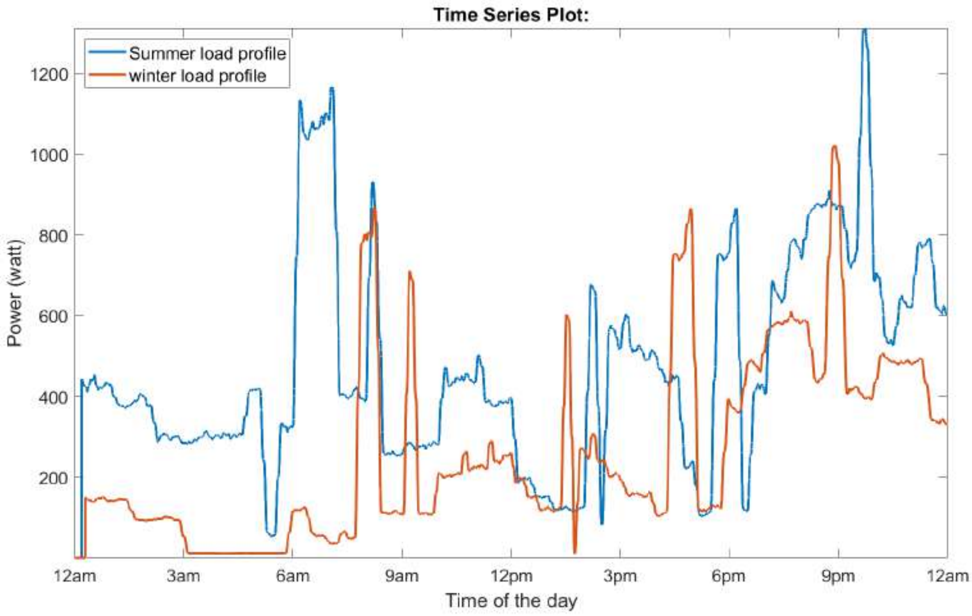


Fig. 3.5 Summer and winter season load profile of the house

profile. The 24 hour version is slightly distorted from the original load profile because of taking just hourly data of this load profile. The 24 hour version of the load profile is given in **Fig. 3.6**.

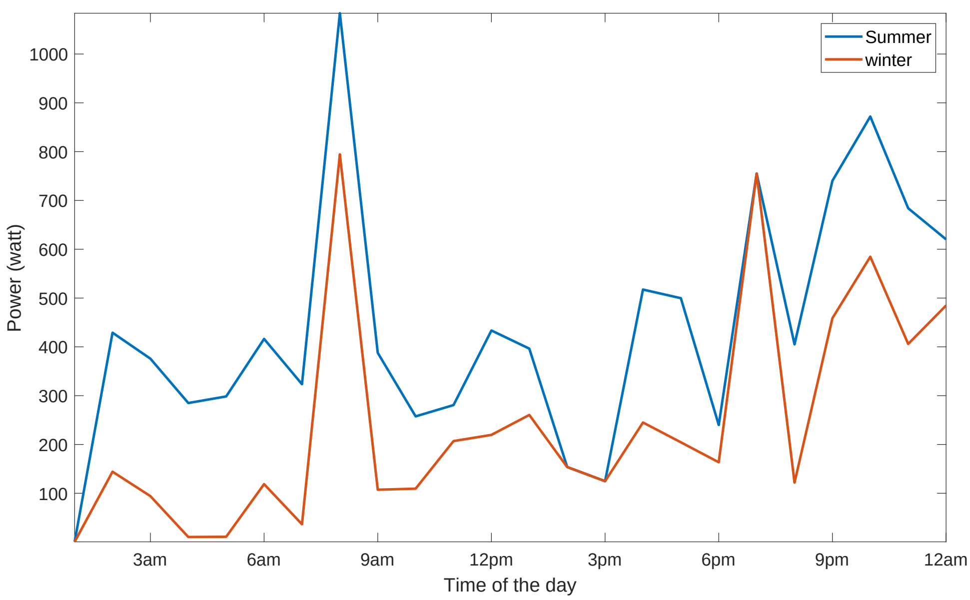
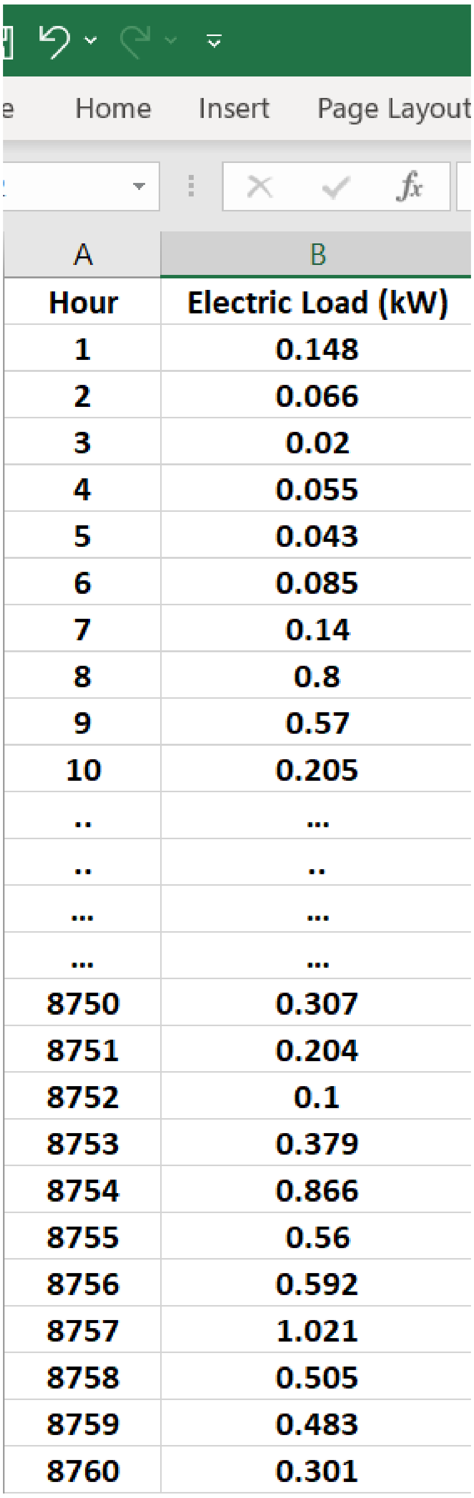


Fig. 3.6 24 hour version of the Summer and winter season load profile of the house

3.3 Yearly Load Profile from 24 H;our Load Profile for REopt Simulation



Hour	Electric Load (kW)
1	0.148
2	0.066
3	0.02
4	0.055
5	0.043
6	0.085
7	0.14
8	0.8
9	0.57
10	0.205
..	...
..	..
...	...
...	...
8750	0.307
8751	0.204
8752	0.1
8753	0.379
8754	0.866
8755	0.56
8756	0.592
8757	1.021
8758	0.505
8759	0.483
8760	0.301

Fig. 3.7 Yearly load profile template for REopt

For making a yearly load profile of this house we have to upload an excel spreadsheet in REopt similiar to this one shown in **Fig. 3.7**. In Bangladesh, generally summer season starts from the beginning of March and end at the end of October. A total of more than 8 months long summer. On the other hand winter season starts at the middle of November and ends at the middle to end of February. A total of 3 to 3.5 months. So, based on this summer and winter season load profile we had to place those hourly load profile data. But there are some problems in this direct approach that is this load profile highly varies and very much unpredictable from time to time. To overcome this issue and to make it unpredictable, there can be several approaches, for example -

1. Observing the load profiles of this consumer for a whole year and then using those data to simulate 365 days simulation in excel and simulink to produce 365 individual load profiles. Finally using those data in the REopt template. But this approach is not practical at all. Moreover a single years load profile won't be the same of the upcoming years because it always varies. This approach will be more or less than around 80% accurate for this particular user.

2. Observing someone's load profile for few days. Then based on the observation taking an average usage case and making an average load profile. Then converting it for the whole year keeping different seasons in mind and modifying accordingly. For this approach - different seasons data, random sequencing can be used together. This approach can yield a result which will be around 60 to 70% accurate.

We have followed the second approach and it is the practical one to work with. Although the accuracy of the load profile is around 70% but it eventually represents the power usage scenario of a middle class house in Bangladesh.
Yearly load profile of the house is shown in **Fig. 3.8**. This figure is very hard to visualize because of the densely populated data. For getting a better overview of the load profile a monthly representation of February mid to March mid load profile is shown in **Fig. 3.9**. A weekly representation of load profile for both summer and winter is shown in **Fig. 3.10** and **Fig. 3.11**. From these figures we can have a concept of the electricity usage of that particular house throughout the year.
Finally, a comparison between the summer and winter weekly load profile is shown in **Fig. 3.12**. Based on this load profile and other load profiles similar to this one we are going to optimize the renewable energy scenario of Bangladesh and find out the hindrances towards it.

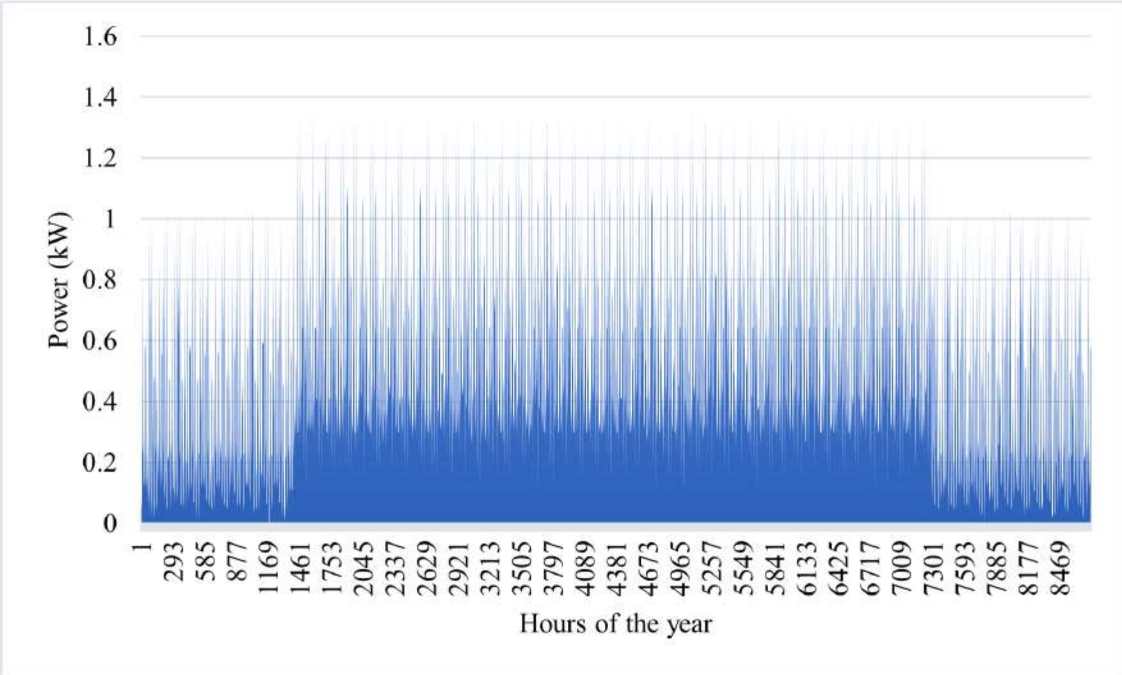


Fig. 3.8 Yearly load profile

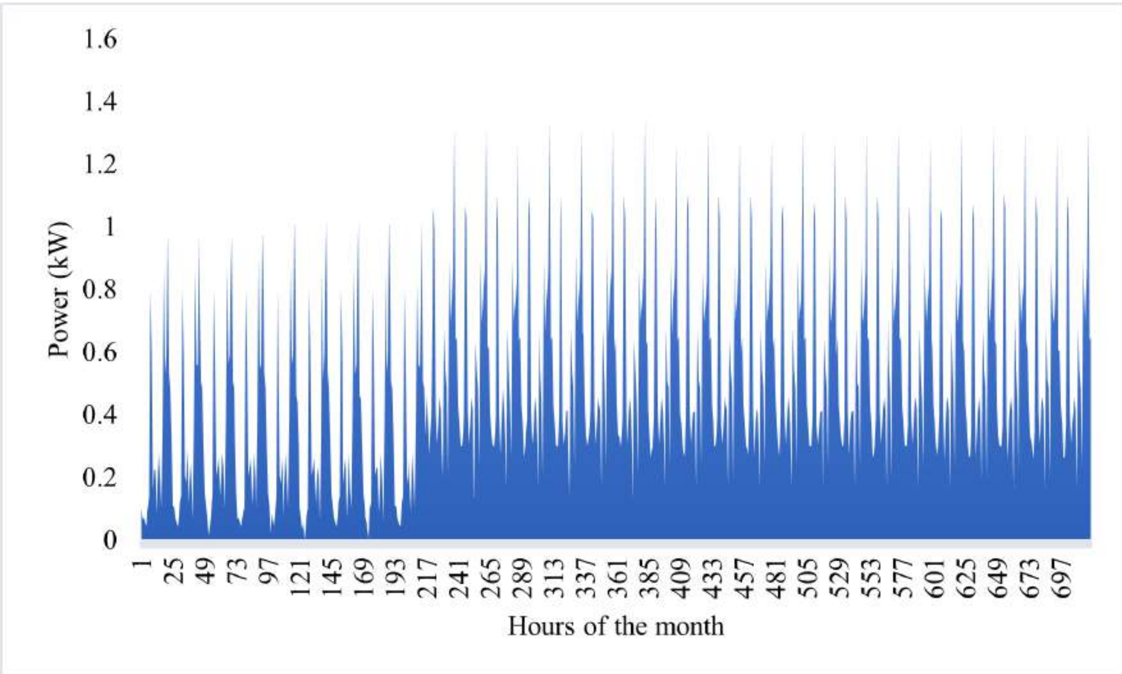


Fig. 3.9 Load profile from mid February to mid March

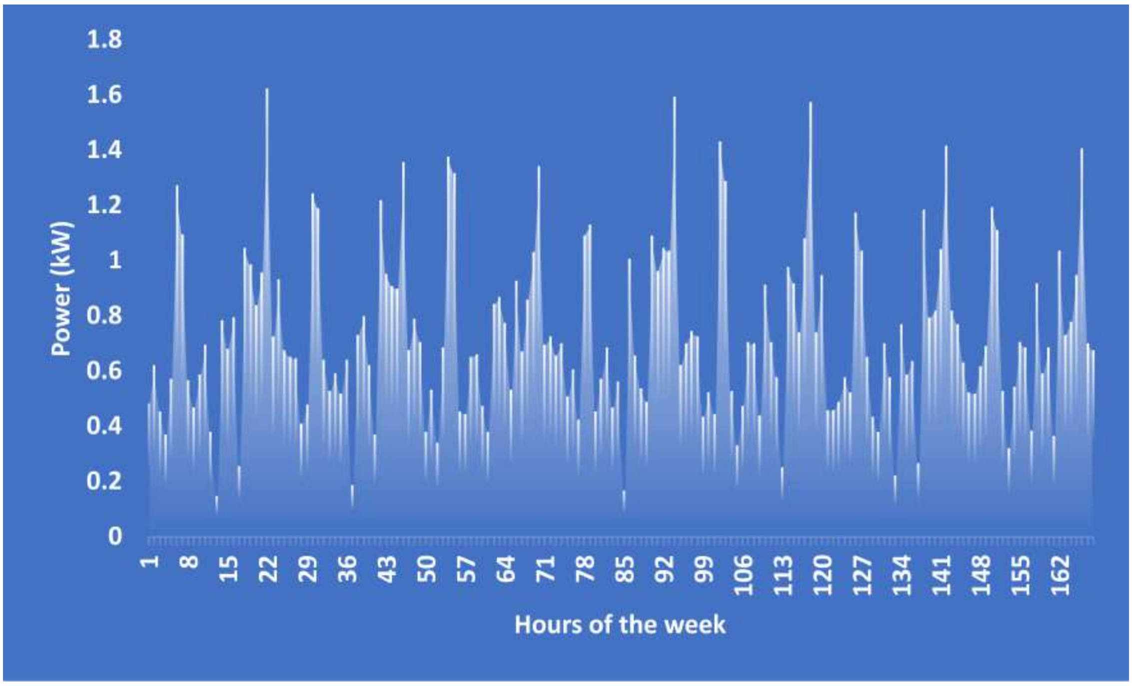


Fig. 3.10 Summer weekly load profile

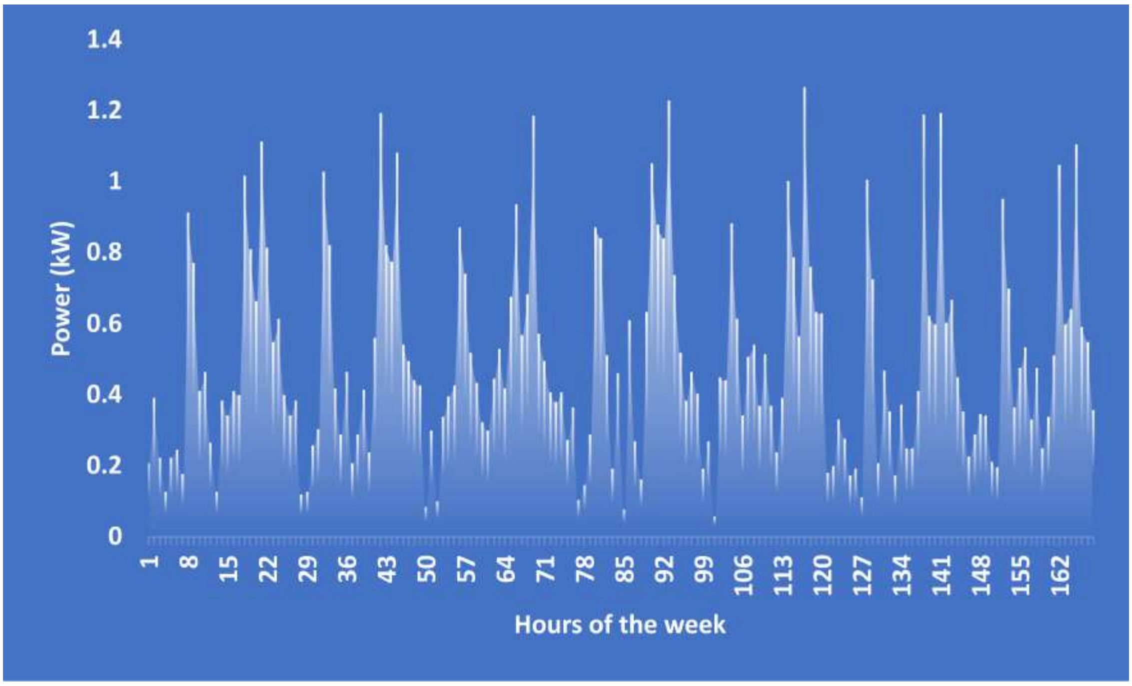


Fig. 3.11 Winter weekly load profile

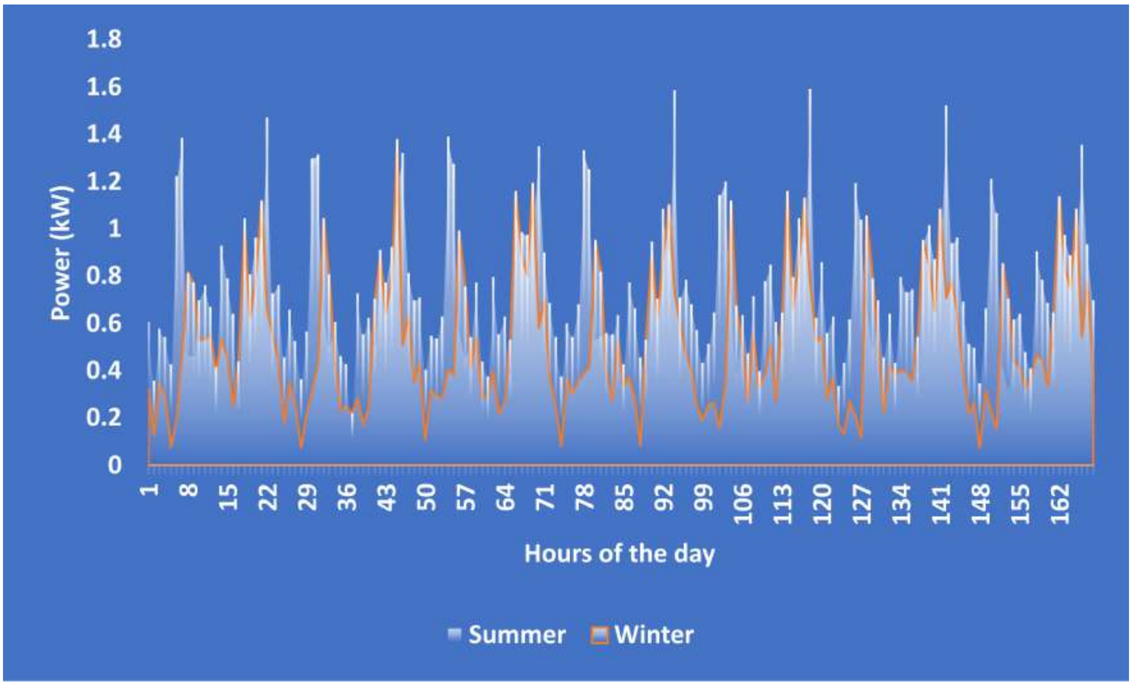


Fig. 3.12 Summer vs winter weekly load profile

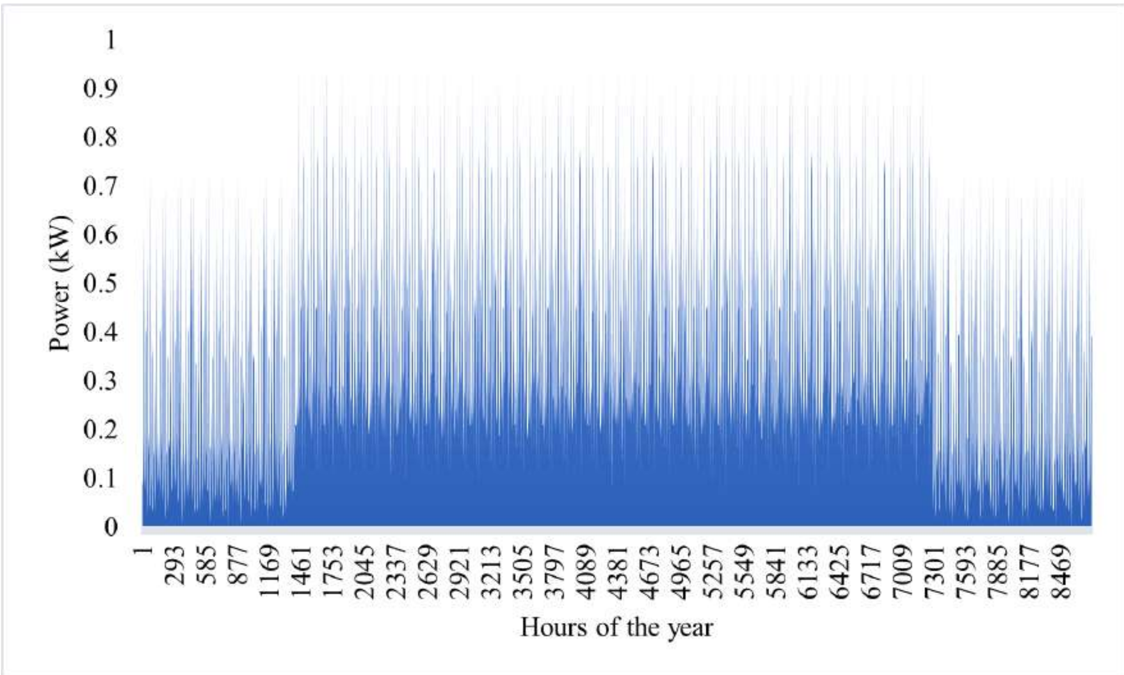


Fig. 3.13 Load profile of the residential home with slightly less power consumption

3.4 Other load profiles

For this work, we have considered 1 residential and 1 small business load profile. We have discussed the procedure of making 1 load profile in details. Here we will show the load profiles of the smaller residential home and small business.

3.4.1 Small Business/Office

We have considered a small business where the peak load is around 20 kW. For such a consumer we have considered an off day in every week that is Friday. The yearly load profile is given below **Fig. 3.14**. The weekly power consumption scenario of this

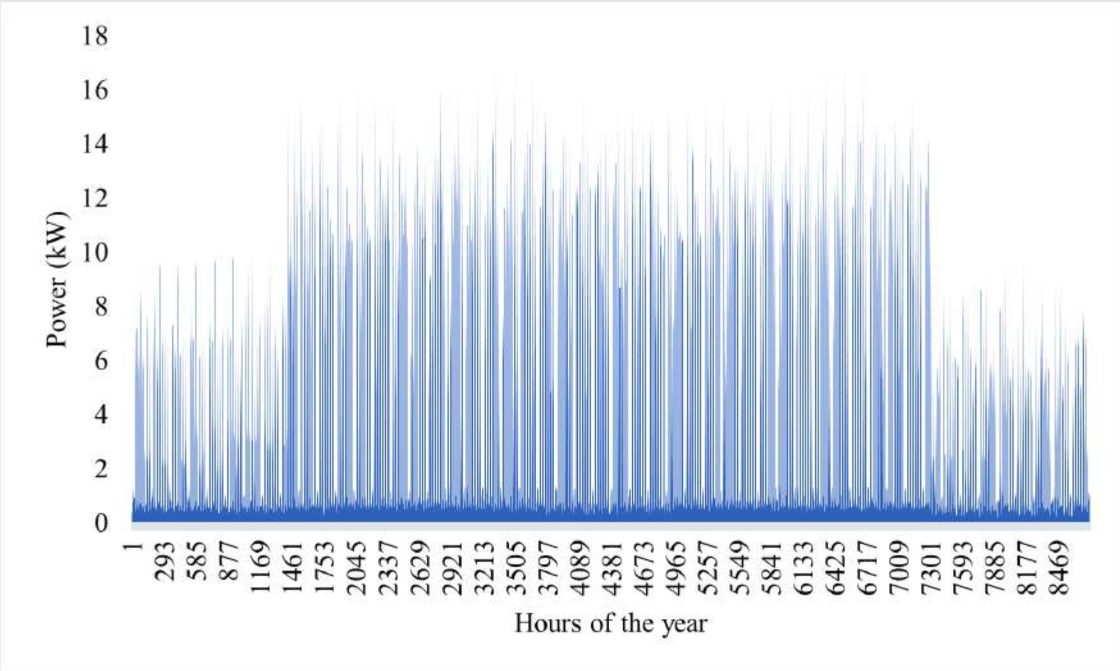


Fig. 3.14 Yearly load profile of a small business

business owner both in summer and winter is shown in **Fig. 3.15**. We can see that while the working hours of the week the power consumption is at a high level. And at the end of the week the power consumption is very low. Infect every day at night wile the working hour is off then also the power consumption is very low like 22nd hour to 29th hour of the hour of the week. Based on these three load profile we will make our optimization in REopt lite.

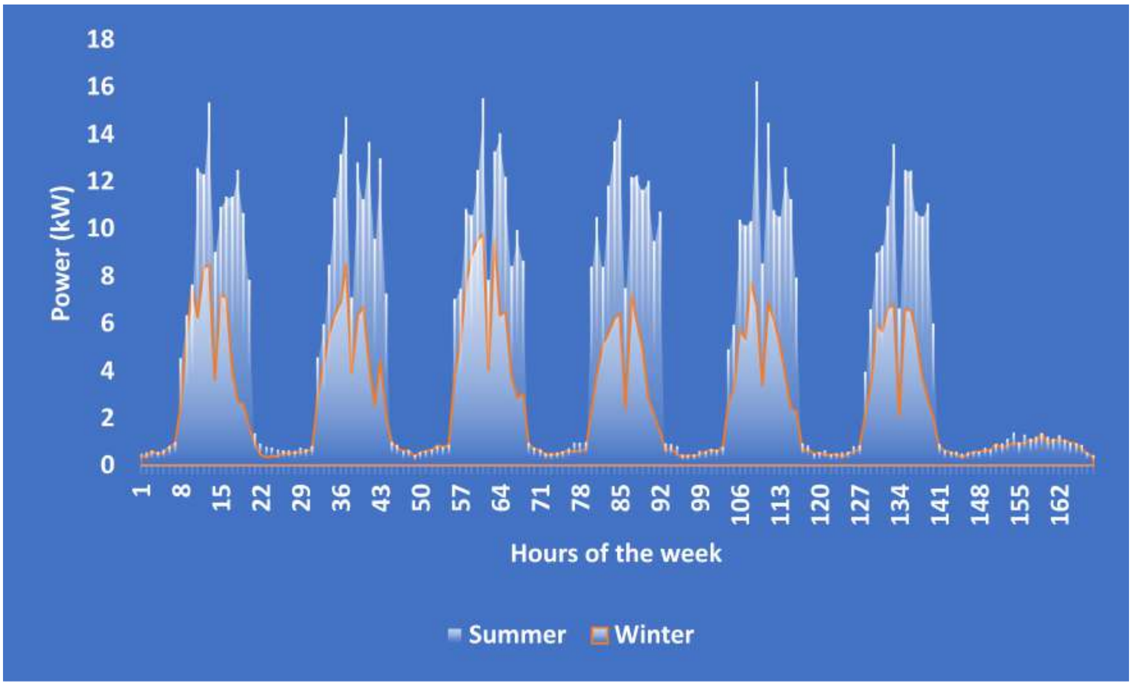


Fig. 3.15 Weekly load profile of the small business in summer and winter

3.5 Tariff rate

We have considered the BPDB tariff rate stated in [31] for this analysis. Two tariff rates were made - one is for residential and another one is for small business.

CHAPTER 4

RENEWABLE OPTIMIZATION IN REOPT LITE WEB TOOL

4.1 Introduction

REopt is the short form of renewable energy optimization. It is a tool that can be used both in online and offline to determine the various parameters of renewable energy projects such as economic viability, resilience analysis, measuring the environment impacts of the project and so on based different variables and technologies such as pv, wind, energy storage, chp, diesel engine [32]. It can suggest technologies, system size and dispatch strategies that will be beneficial for the project over it's life cycle. REopt Lite also estimates the amount of time on-site generation and storage can sustain the site's critical load during a grid outage and allows the user the choice of optimizing for energy resilience or clean energy goals. It is primarily used to inform project development decisions and to support research on the factors that drive project feasibility for market development and policy analysis.

4.2 Optimization Scenarios

We have considered four scenarios that are suitable with the objectives of this study. For all three load profiles we have simulated these scenarios.

1. On grid PV - no net metering - 15 years life time operation
2. On grid PV with net metering - 15 years life time operation
3. On grid PV with net metering - 25 years life time operation generator
4. On grid PV with net metering and govt incentives - 25 years life time operation generator

4.3 Residential Consumer

In chapter 3, we have discussed about the residential load profile in a very detailed manner. Here we will discuss about the input parameters and the output of the simulation.

4.3.1 Scenario 1

Scenario 1 represents the current state of SHS in Bangladesh. The input parameters for the scenario 1 is given below as a exported pdf file as exported from REopt. Here all the input parameters are given that were inserted and those were automatically taken as defaults.

Technologies Selected	
PV ☀	

Site and Utility	
Site Location	Chattogram, Bangladesh (22.356851, 91.7831819)
PV & wind space available	Roofspace
Custom electricity rate	f BPDB

Load Profile	
Typical electric load profile type	uploaded
Uploaded typical electric load profile	home1 summer13 winter8

Financial	
Analysis period (years)	15
Host discount rate, nominal (%)	0%
Host effective tax rate (%)	0%

Renewable Energy and Emissions	
Annual CO_2 grid emissions factor (lbs CO_2/kWh)	1.54324
Annual NOx grid emissions factor (lb NOx/kWh)	0.00881849
Annual SO_2 grid emissions factor (lb SO_2/kWh)	0.0154324

PV	
System capital cost ($/kW)	1200.0

Federal percentage-based incentive (%)	0%
Federal rebate ($/kW)	0.0
Incentive duration (years)	0
MACRS bonus depreciation	0%
MACRS schedule	No MACRS

Defaults

Default Inputs

The results are based on the following default inputs.

Site and Utility	
PV & wind roofspace available	Unlimited
Existing heating system fuel type	natural gas
Net metering system size limit (kW)	N/A
Wholesale rate ($/kWh)	N/A
Solver optimality tolerance (%)	0.1%

Load Profile	
Load adjustment (%)	100%

Financial	
Electricity cost escalation rate, nominal (%)	2.3%
O&M cost escalation rate (%)	2.5%
Third Party Ownership	false
Third-party owner discount rate, nominal (%)	8.3%

Third-party owner effective tax rate (%)	26%

Renewable Energy & Emissions	
Annual PM2.5 grid emissions factor (lb PM2.5/kWh)	N/A
Include Climate In Objective	false
Include Health In Objective	false
Count renewable electricity (RE) exported to the grid towards annual RE goals?	true
Count electricity exported to the grid towards emissions offsets?	true
CO_2 cost (\$/t CO_2)	51.0
On-site fuel burn NOx cost (\$/t NOx)	0
On-site fuel burn SO_2 cost (\$/t SO_2)	0
On-site fuel burn PM2.5 cost (\$/t PM2.5)	0
Grid emissions NOx cost (\$/t NOx)	0
Grid emissions SO_2 cost (\$/t SO_2)	0
Grid emissions PM2.5 cost (\$/t PM2.5)	0
CO_2 cost escalation rate, nominal (%)	4.22%
NOx cost escalation rate, nominal (%)	0.00%
SO_2 cost escalation rate, nominal (%)	0.00%
PM2.5 cost escalation rate, nominal (%)	0.00%

PV	
Existing PV systems size (kW)	N/A
Type of load profile	N/A
O&M cost (\$/kW per year)	\$16

Minimum new PV size (kW DC)	0
Maximum new PV size (kW DC)	Unlimited
Module type	Standard
Array type	Rooftop, Fixed
Array azimuth (deg)	180
Array tilt (deg)	10
DC to AC size ratio	1.2
System losses (%)	14%
PV generation profile	N/A
Federal maximum incentive (%)	Unlimited
Federal maximum rebate ($)	Unlimited
State percentage-based incentive (%)	0%
State maximum incentive ($)	Unlimited
State rebate ($/kW)	$0
State maximum rebate ($)	Unlimited
Utility percentage-based incentive (%)	0%
Utility maximum incentive ($)	Unlimited
Utility rebate ($/kW)	$0
Utility maximum rebate ($)	Unlimited
Production incentive ($/kWh)	$0
Maximum incentive ($)	Unlimited
System size limit (kW)	Unlimited
PV Station Search Radius (mi)	Unlimited
Can Net Meter	Can Net Meter

From the data table we see that location, technology installing site information, tariff rate, load profiles, life cycle time, GHG emissions data and per kW capital cost of the system data was given as input for the simulation. Based on these inputs optimization report has been prepared by REopt.

REopt: Renewable Energy Integration & Optimization

Link to Results Page

Disclaimer

Help Manual | API | Open Source Code | User Forum | Log In/Register

Results for Your Site

Your site at Chattogram Bangladesh evaluated on April 9, 2022

These results from REopt summarize the economic viability of PV, wind, battery storage, and/or CHP at your site. You can edit your inputs to see how changes to your energy strategies affect the results.

Your recommended solar installation size

1 kW

PV size

Measured in kilowatts (kW) of direct current (DC), this recommended size minimizes the life cycle cost of energy at your site.

This optimized size may not be commercially available. The user is responsible for finding a commercial product that is closest in size to this optimized size.

Your potential life cycle savings (15 years)

This is the net present value of the savings (or costs if negative) realized by the project based on the difference between the total life cycle costs of doing business as usual compared to the optimal case.

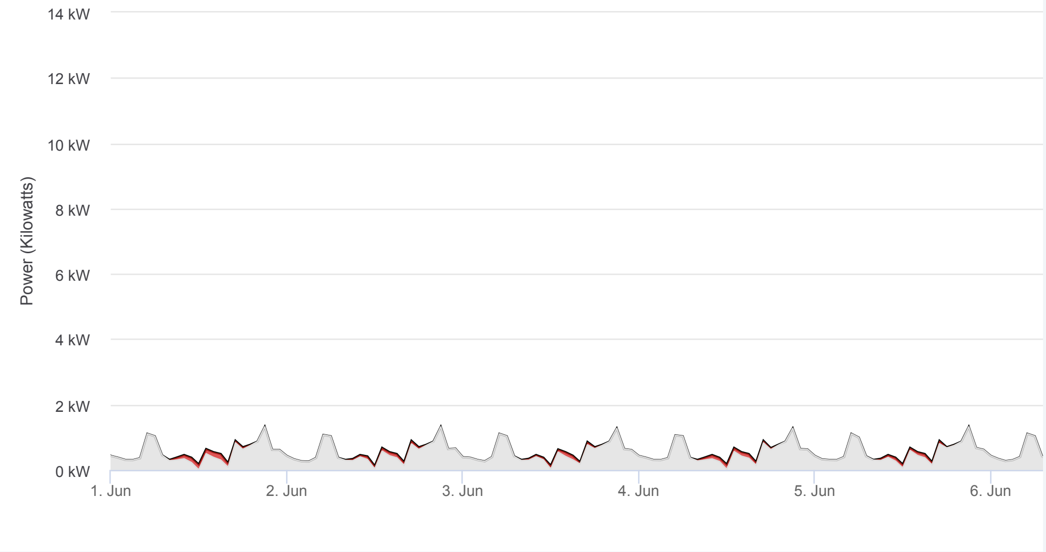
$36

View citation

System Performance Year One

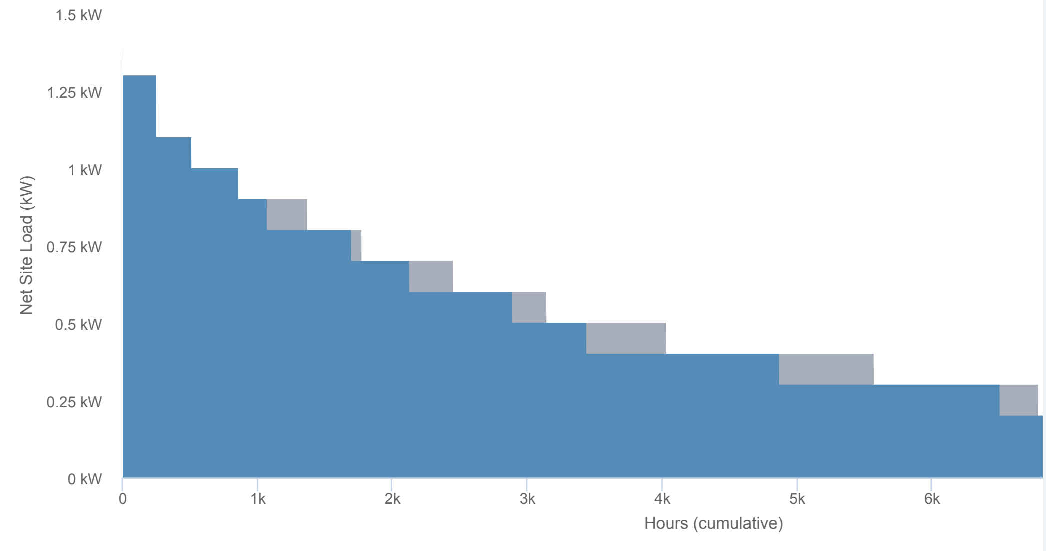
System Performance Year One

This interactive graph shows the dispatch strategy optimized by REopt for the specified outage period as well as the rest of the year. To zoom in on a date range, click and drag right in the chart area or use the "Zoom In a Week" button. To zoom out, click and drag left or use the "Zoom Out a Week" button.



Net Load Duration

This interactive graph shows the reduction in peak load that occurs when the REopt recommended technologies are implemented. To zoom in on a date range, click and drag right in the chart area. To zoom out, click and drag left or use the "Reset zoom" button.



Download Load Duration Spreadsheet

Download All Dispatch Data

Results Comparison

Results Comparison

These results show how doing business as usual compares to the optimal case.

	Business As Usual	Financial	Difference
System Size			
PV Size	0 kW	1 kW	1 kW
Energy Production and Fuel Use			
Average Annual PV Energy Production	0 kWh	367 kWh	367 kWh
Average Annual Energy Supplied from Grid	4,299 kWh	3,943 kWh	-355 kWh

Renewable Energy Metrics			
Annual Renewable Electricity (% of electricity consumption)	0%	8%	8%
Climate & Health Emissions			
Total CO_2 Emissions in Year 1	3 tons	3 tons	0 tons
Percent Reduction in CO_2 Emissions from BAU	N/A	8.27%	8.27%
Lifecycle Costs of Climate Emissions	$2,938	$2,695	-$243
Lifecycle Costs of Health Emissions	$0	$0	$0
Year 1 Utility Electricity Cost — Before Tax			
Utility Energy Cost	$246	$224	-$22
Utility Demand Cost	$5	$5	$0
Utility Fixed Cost	$47	$47	$0
Utility Minimum Cost Adder	$0	$0	$0
Total Year 1 Utility Cost - Before Tax	$298	$276	-$22
Life Cycle Cost Breakdown			
Technology Capital Costs + Replacements, After Incentives	N/A	$288	$288
O&M Costs	$0	$70	$70
Total Utility Electricity Cost	$5,396	$5,002	-$394

Lifecycle Costs of Climate Emissions (included in objective)	$0	$0	$0
Lifecycle Costs of Health Emissions (included in objective)	$0	$0	$0
Summary Financial Metrics			
Total Upfront Capital Cost Before Incentives	N/A	$288	$288
Year 1 O&M Cost, before tax	$0	$4	$4
Total Life Cycle Costs	$5,396	$5,360	-$36
Net Present Value	$0	$36	$36
Payback Period	N/A	13.54 yrs	13.54 yrs
Internal Rate of Return	N/A	1.5%	1.5%
PV Levelized Cost of Energy	N/A	$0.065/kWh	$0.065/kWh

Clean Energy Outputs

Inputs

Your Inputs

The results are based on the following user supplied inputs.

Energy Goals
Cost-Savings **$**

The key points to be noted in this large detailed result sections are -

Table 4.1 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

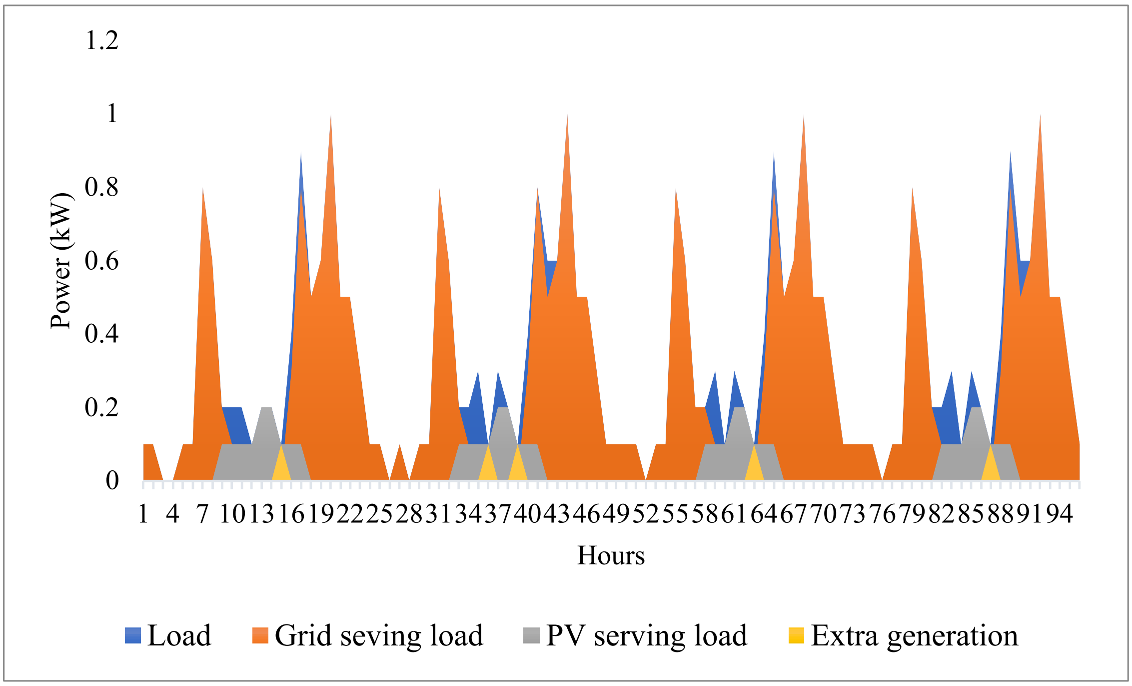


Fig. 4.1 Power consumption of residential consumer during scenario 1

From this result summary given in **Table 4.1**, every parameters are quite familiar and fair except system size and capital cost. Although the system size is showing 1 kW but actually it is not 1 kW. Rather it is a round figure. We can understand this easily from the system capital cost value. This simulation doesn't count any incentive, tax or financial aid. So, per kW PV capital cost input value was 1200 USD. Hence, 288 USD counts one fourth of the size of 1 kW. Actual PV size recommended by REopt is around **250** W system. We can also be sure about this calculation from the annual PV production value. A 1 kW system will obviously generate far more electricity than 367 kWh stated in the result section. Annual production of 367 kWh can be justified only with this 250 W system size, not with the 1 kW system size.

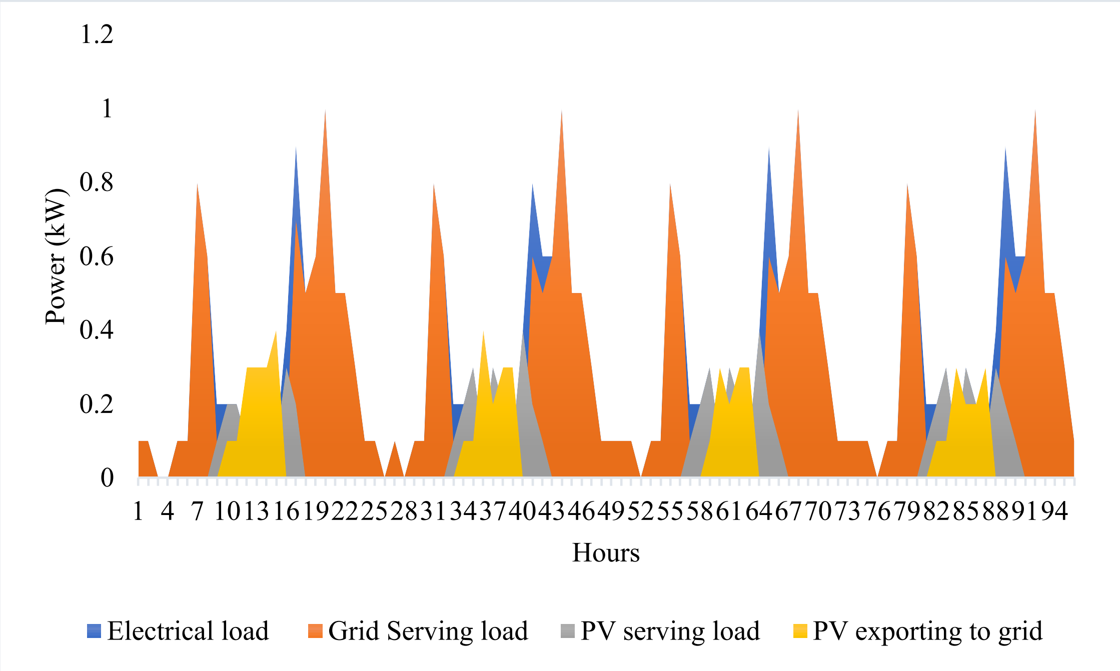


Fig. 4.2 Power consumption of residential consumer during scenario 2

4.3.2 Scenario 2

Scenario 2 has been simulated considering net metering in mind. That means the extra generation shown in **Fig. 4.1** will be exported to the grid. Bangladesh govt has made a net metering guideline policy in 2018 which has not been implemented yet [33]. So, we have implemented net metering for a life span of 15 years. The result summary of scenario 2 is given in **Table 4.2**.

The power flow situation of scenario 2 is shown in **Fig. 4.2**.

4.3.3 Scenario 3 and 4

Scenario 3 is basically an extension of scenario 2. Scenario two considered 15 years life cycle of a pv system with net metering while scenario 3 considered 25 years life cycle. The summary of scenario 3 and 4 are presented in tabular form in **Table 4.3** and **Table 4.4** respectively. A comparative result analysis on the results will be presented in chapter 5.

Table 4.2 Result of scenario 2 of residential consumer

Parameters	Value
potential life cycle savings	78 USD
system size	.65 kW
capital cost of the system	834 USD
average annual PV power production	1,065 kWh, 25% of the total system
per kWh PV energy cost	0.065 USD
CO_2 emission reduction in life cycle	about 14 tons ≈ 728 USD
total first year saving in electricity bill	61 USD
total life cycle cost before installing PV	5396 USD
total life cycle cost after installing PV	5,318 USD
payback years	13.98 years

Table 4.3 Result of scenario 3 of residential consumer

Parameters	Value
potential life cycle savings	1103 USD
system size	1 kW
capital cost of the system	1200 USD
average annual PV power production	1,495 kWh, 35% of the total system
per kWh PV energy cost	0.047 USD
CO_2 emission reduction in life cycle	about 40 tons ≈ 2003 USD
total first year saving in electricity bill	84 USD
total life cycle cost before installing PV	10163 USD
total life cycle cost after installing PV	9060 USD
payback years	14.68 years

Table 4.4 Result of scenario 4 of residential consumer

Parameters	**Value**
potential life cycle savings	1361 USD
system size	1 kW
capital cost of the system	1020 USD
average annual PV power production	1,495 kWh, 35% of the total system
per kWh PV energy cost	0.045 USD
CO_2 emission reduction in life cycle	about 40 tons ≈ 2003 USD
total first year saving in electricity bill	84 USD
total life cycle cost before installing PV	10163 USD
total life cycle cost after installing PV	8802 USD
payback years	13.86 years

4.4 Small business

The output result for scenario 4 has been depicted in **Fig. 4.3**. The result of scenario 4 has been shown in **Table 4.4**. If we install a system size of 1kW with PV serving the load as well as PV exporting to the grid will be as below. And it will be quite beneficial economically.

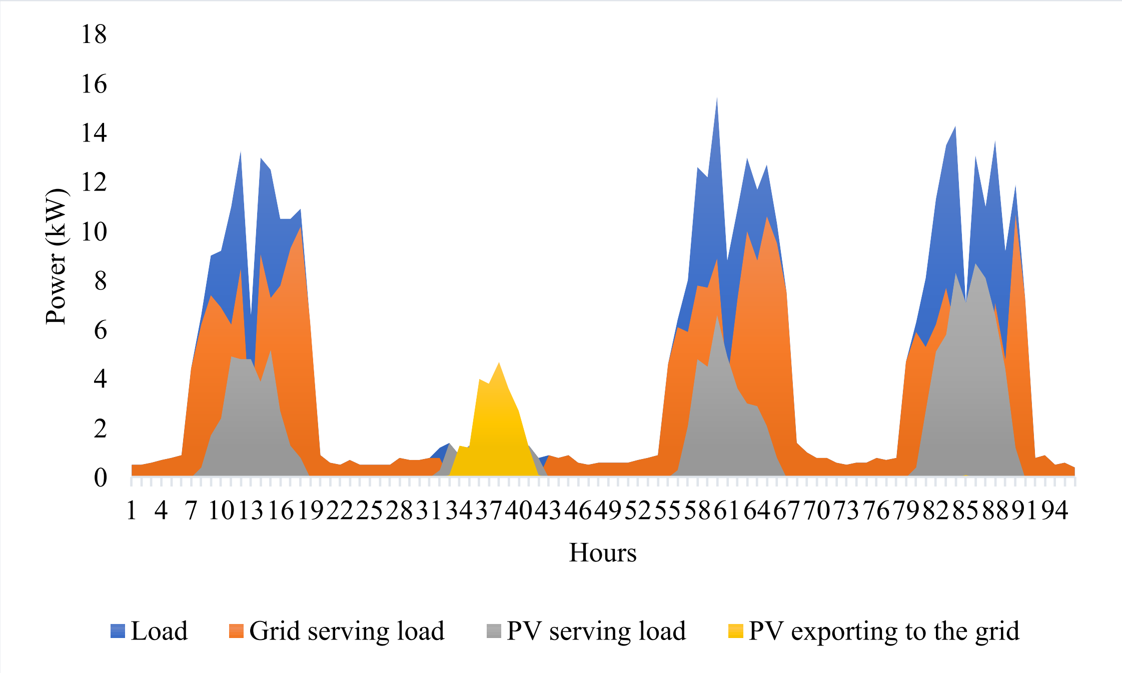


Fig. 4.3 Power consumption of small business consumer during scenario 4

CHAPTER 5
RESULT AND ANALYSIS

5.1 Introduction

In this chapter, we will present the key findings of this study and try to analyze the results according to the objectives of this work. In chapter 4, we have shown the different results of the four scenarios that we have considered for this study. We have taken ten variables from the REopt result and showed the load profiles of those results. Here we will compare the results to come to a conclusion.

5.2 Residential Home Results Comparison

Table 5.1 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

From this comparison stated in **Table 5.1**, it is safe to say that scenario 3 and scenario 4 is the best option available for one who is willing to install SHS.

5.3 Small Business Results Comparison

Summary of small business data has been presented in **Table 5.2**.

Table 5.2 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**

5.4 Result Analysis

From the comparative analysis of the REopt simulation results we have observed the following things -

1. Both for residential and small village scenario 4 seems attractive SHS installation approach. Especially the small businesses can be greatly benefited by installing on site PV if spaces are available.
2. Scenario 1 is the current situation of our country. Since, no net metering is available hence installing large SHS can ultimately not be beneficial because during low demand lots of power generated will be wasted without any storage and exporting option. Hence, for the residential scenario 1, we see that REopt suggests a very small size system of only 250 W.

3. In case of business model, even at this current situation installing on site PV can be beneficial. It's because business peak hour is parallel to solar peak hour. But the total life time saving potential is not very attractive in this case which is main factor we don't see lots of small scale on site pv installed by business farms.
4. We haven't added any climate cost with the lifetime anlysis of the scenarios since the mass population is not really that much interested in this regard. But we see that, just the climate cost benefit is more than the total capital cost of the system in some cases.

CHAPTER 6
CONCLUSION

6.1 Introduction

In this work we have tried to visualize the factors that are primarily opposing the mass implementation of SHS through REopt lite tool analysis of some actual load. We have created actual load profiles of users and simulate them with our current policies for installing SHS which gives us an identical output to the real situation those are responsible for opposing SHS in Bangladesh. Then we have created three hypothetical scenarios that can be introduced by our policy makers to make SHS popular.

6.2 Conclusion

To identify the current state of SHS in the world, especially developed and developing countries and comparing the situation of Bangladesh in this regard. We have studied couple of papers and identified some obstacles. because of these problems pv systems couldn't gain popularity and necessary trust among mass population. Govt policies and lack of incentives as well as good financial models are also big hindrance towards SHS. From this study we have found some key points that may be effective to make SHSs popular in our country. Introduction of net metering in our existing renewable policies can be a game changer since both for residential and business purpose it makes the system economically very attractive. Small scale SHS don't seem very attractive from economical perspective.Residential users whose monthly electricity consumption is around 250 kWh or above can think of installing on grid pv and it will be economically profitable.

Business users can install pv and get beneficial even with the existing policies since the peak pv hour and peak electric hour for business is parallel to each other. On site pv will be even more attractive towards business users if net metering becomes available because almost sll business maintain a weekly off day. During off day 90% of the power generated by PV can be exported to this grid. High capital cost could still be a barrier for installing SHS. Introduction of better financial mechanisms will also increase the attractiveness of SHS. Rise of environment consciousness will make SHS even more lucrative not only just for environment related concerns but alos for economic reasons.

6.3 Limitations

The primary limitations of this study lies in extensive literature review regarding this study. We haven't found any particular study using REopt that focuses on the similar objectives. However, we have found interesting literature focusing on other objectives like resilience analysis of a microgrid [34].

One particular weakness of this study is that REopt lite suggests system size in rounded figure. For, small scale analysis accurate result for system size is not always right. But based on other data actual system size can be determined that we have done for residential scenario 1 result analysis.

Addition of more scenarios along with more load profiles could strengthen the conclusion of this work. But what we have presented, we believe it's enough to justify our conclusion.

6.4 Future Scopes

We have analyzed the economic viability of SHS considering the application being in residential and small business. Our primary focus was economic analysis. But there are potential scopes of clean energy and system resilience analysis. Beside this except residential and small business analysis, economic viability analysis of different sites, fulfilling clean energy goals and resilient analysis of different sits can be studied.

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APPENDIX

7.1 Winter load profile modification

Listing 7.1 Winter load profile code

```
x=1.2:.00001:2.4;
y =2.^x;
% plot(x,y)
for j=1:120001
    myax(j)=1.2 + ((y(j)-y(1))/(y(120001)-y(1)))*1.2;
end
for k=1:120001
    s2(k)=myax(120002-k);
end
for p=1:120001
    s3(p)=abs(2.4-s2(p));
end
xdata=zeros(size(rlpdata));
for m=1:120001
    xdata(m)=s3(m);
end
for n=120002:240001
    xdata(n)=myax(n-120001);
end
```