Chapter 14
Small-Scale Solar Solutions for Energy Resilience in Bangladesh

Md Rumi Shammin and A. K. Enamul Haque

Key Messages

- Solar home systems (SHSs) offer a cost-effective, climate-friendly alternative power source in off-grid communities.
- SHS serve both climate adaptation and mitigation as a win–win solution.
- There are opportunities for SHS to accomplish multiple sustainable development goals (SDGs) as co-benefits.
- Innovative strategies can be developed to make SHS more accessible and equitable in rural communities.

M. R. Shammin (✉)
Environmental Studies Program, Oberlin College, Oberlin, OH, USA
e-mail: rumi.shammin@oberlin.edu

A. K. E. Haque
Department of Economics, East West University, Dhaka, Bangladesh
e-mail: akehaque@gmail.com

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14.1 Introduction

> We are like tenant farmers chopping down the fence around our house for fuel when we should be using Nature's inexhaustible sources of energy – sun, wind and tide … I'd put my money on the sun and solar energy.
>
> — Thomas Edison.[1]

Solar power is a key piece of the puzzle as humanity confronts climate change and strives to transition to a just, sustainable, and decarbonized future. The technology has improved, costs have become competitive, and implementation rates have grown exponentially. Global solar photovoltaic capacity increased from 15 GW in 2008 to 505 GW in 2018—generating ~ 640 TWh or 2.4% of global electricity annually (REN 21, 2019). However, there is still a long way to go for solar and other climate-friendly renewables, which currently account for 11% of total primary energy supply in the world, to displace the 85% coming from carbon intensive fossil fuel sources (BP, 2019). This shift will require humanity to make bold commitments and find creative ways of accelerating the adoption of renewable energy across a wide spectrum of demographic, economic, social, geopolitical, and environmental circumstances. While China, the United States, and the European Union lead solar power generation as of 2019, distributed solar installations in homes, commercial buildings and industrial facilities are expected to double by 2024 accounting for 50% of total growth in solar power (IEA, 2019). Expansion of solar powered electricity across the globe is not homogeneous. In countries like China and the USA, it is mostly driven by commercial interests to supply electricity to the grid. Europe has additionally focused on the household level using net-metering. In South Asia, most installations are for at-home consumption using rooftop solar systems.

Deconstruction of the recent upsurge of solar power exposes very different contexts in which the technology is manifesting—revealing innovative opportunities to leverage solar solutions to achieve climate mitigation, support climate adaptation, build community resilience, and help accomplish the United Nations Sustainable Development Goals (United Nations, n.d.). This chapter documents lessons learned from small-scale solar solutions in remote rural climate vulnerable communities in Bangladesh.

14.2 Powering the Poor in a Changing Climate

Globally, 789 million people live without electricity and hundreds of millions more live with insufficient or unreliable access to it (The World Bank, 2020) More than 1.2 billion people including 40% of the world's rural population living in off-grid

[1] Attributed in: Newton, J. D. (1989). Uncommon friends: life with Thomas Edison, Henry Ford, Harvey Firestone, Alexis Carrel, and Charles Lindbergh. Mariner Books.

rural areas in developing and less developed countries do not have reliable access to electricity (IEA: World Energy Outlook, 2016).

Since energy-related carbon emissions are primarily responsible for global climate change, grid expansion to deliver electric power to off-grid communities may lead to continued dependence on existing fossil fuel-based electricity sources and potentially incremental greenhouse gas (GHG) emissions (Komatsu et al., 2011). This presents a philosophical and practical dilemma: on the one hand, these communities have near-zero contribution to the current causes of climate change and, therefore, are least obligated to make major compromises to mitigate GHG emissions; on the other hand, many of these rural communities are in areas that are highly vulnerable to rising sea levels and the effect of more frequent extreme weather conditions caused by global climate change. Any initiative, local or global that reduces the impact of climate change would therefore be beneficial to them. Hence, SHS has the potential for local mitigation initiatives to reduce future local impacts.

In Bangladesh as of 2018, ~ 15% of 166 million residents do not have access to electricity, a decrease from ~ 39% in 2014 (The World Bank, n.d.). This is most likely due to increased production capacity and grid expansion, as well as growth of solar home systems (SHSs) . The SHS installations have focused on off-grid rural communities and served predominantly poor and marginalized communities.

14.3 Homes Powered by the Sun

Solar home systems (SHSs), installed on rooftops of individual households, offer a win–win solution for rural electrification and climate mitigation. SHS have been evolving worldwide since the late 70s and early 80s. The world's first solar electric neighborhood in Gardner, Massachusetts, consists of 30 solar homes—each fitted with a 2 kW grid connected system. The Pal Town Solar City in Japan has 550 homes—each fitted with a 4 kW system (Kamal, 2011).

The number of small-scale SHS projects has been steadily increasing in Asia, South America, and Africa since the 90s with nearly a million SHS installed by the year 2000. This growth has accelerated in the new millennium—with significant momentum documented in several South Asian countries including Sri Lanka, India, and Bangladesh (Komatsu et al., 2011). With annual solar radiation of more than 1900 kWh/m^2 and average daily solar radiation of 4–6.5 kWh/m^2, SHS are particularly attractive for Bangladesh (Khanam et al., 2018).

To bridge the financing gap for developing medium and large-scale infrastructure and renewable energy projects in Bangladesh, the Infrastructure Development Company Limited (IDCOL) was established in 1997 by the Government of Bangladesh—licensed as a non-bank based financial institution. IDCOL spearheads the dissemination of SHS in Bangladesh through its solar energy program with financial support from the World Bank, Global Environment Facility, Kreditanstalt fürWiederaufbau (KfW), German Agency for International Cooperation (GIZ) formerly known as Gesellschaft für Technische Zusammenarbeit (GTZ), Asian

Development Bank, and Islamic Development Bank. IDCOL started this program in January 2003 with an initial target of financing 50,000 SHS by the end of June 2008. The target was achieved in September 2005, three years ahead of schedule, and two million dollars below budget. IDCOL then revised its target and decided to finance 200,000 SHS by the end of 2009. This was also achieved seven months ahead of schedule. In subsequent years, IDCOL consistently overshot its SHS implementation goals—making it one of the fastest growing renewable energy programs in the world. As of 2019, over 4 million solar home systems (SHS) have been installed in rural off-grid communities in Bangladesh—creating over 70,000 jobs and bringing electric power to more than 18 million people or 11% of the country's population (IDCOL, n.d.). This is about 12.2% of all connected users in Bangladesh (GoB, 2019). Most of these users are low-income and consume a very small amount of electricity at their homes.

The SHS installed in developing countries represent significantly different technologies and scales. While most systems installed in developed countries are grid connected and operate on AC power through an inverter, implementation in off-grid communities in developing countries rely on energy storage in batteries running DC powered appliances through a charge controller. The typical sizes of solar home systems in OECD countries range from 1000 W (1 kW) to roughly 6000 W (6 kW) per household. The size of the SHS installed in rural homes in Bangladesh are orders of magnitude smaller—typically ranging between 20 and 100 W (see Fig. 14.1a, b for a visual comparison).

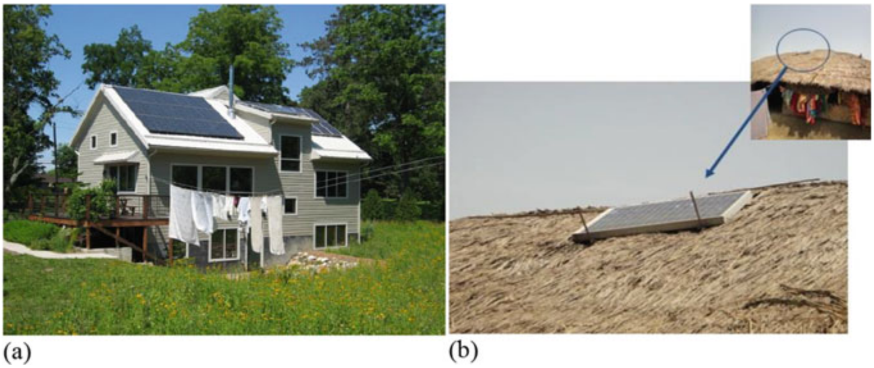


Fig. 14.1 **a** Trail magic in Oberlin, Ohio, USA with a 5.2 kW solar system. **b** Solar home in Batiaghata, Bangladesh with a 40 W solar system. *Photo credit* **a** Carl McDaniel, **b** Md Rumi Shammin

14.4 SHS in Bangladesh: A Closer Look

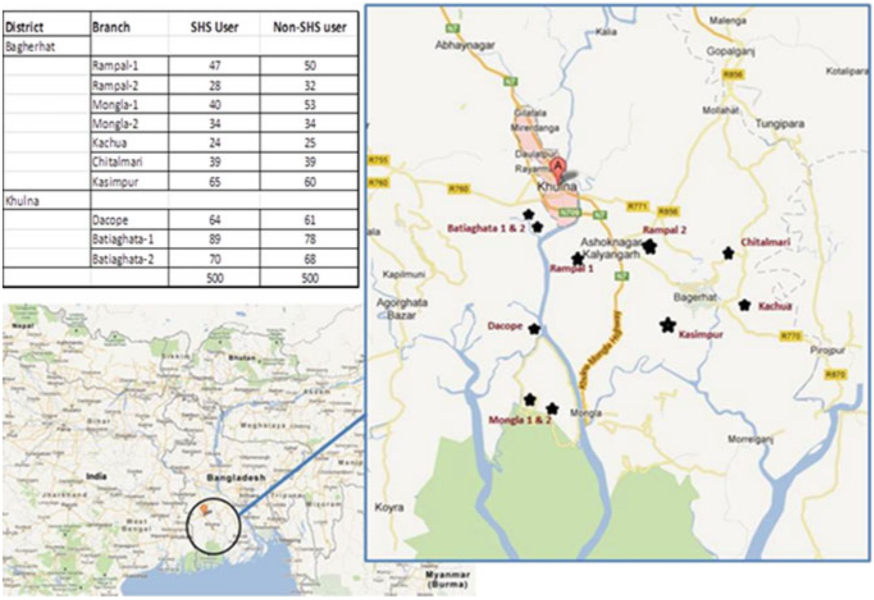
To evaluate potential co-benefits of SHS in the context of climate change, a study was conducted in climate vulnerable coastal communities in the coastal districts of Khulna and Bagherhat in south-eastern Bangladesh in 2012–13. The SHS surveyed were installed by Bangladesh Rural Integrated Development for Grub-Street Economy (BRIDGE)—a partner organization (PO) of IDCOL. Systematic random samples of 1000 households were drawn from ten different BRIDGE project locations. 50% of the surveys ($n = 500$) were carried out with households currently using SHS and the remaining 50% ($n = 500$) of surveys were carried out with SHS non-users randomly selected from the same general area. The purpose of surveying the two groups was to have a control population to analyse changes achieved by SHS and explore untapped future opportunities.

The SHS user survey included questions on demographics (name, age, income, occupation, family size, education, etc.), satisfaction, user-friendliness, cost, maintenance, past energy use, present energy use, quality of life (before/after), idea of alternatives, perception of opportunity cost, distribution of benefits, barriers, equity, etc. The SHS non-user survey included the same questions with appropriate modifications and additional questions on unmet energy needs and willingness to pay for SHS. When available, the head of households was surveyed. In their absence, the spouse of the head of household was surveyed. The final sample count and locations are shown in Fig. 14.2.

Statistical tests indicate that SHS users and non-users are different in terms of their demographic characteristics (Table 14.1). It appears that households that are relatively well-off within these communities adopted the SHS. A similar result was also observed in a study by the World Bank on SHS users in Bangladesh (Asaduzzaman et al., 2013). Finally, informal conversations were carried out with selected public officials, private sector entrepreneurs, representatives of non-government organizations and local people to distill contextual and anecdotal information about the opportunities and challenges of SHS.

14.5 SHS and SDGs: Grassroots Lessons

SHS provide a range of benefits associated with and beyond providing an alternate source of power. These benefits include access to new income generating activities, reduced travel cost (or opportunity cost of time) to buy kerosene, educational benefits for children, increased security, reduced indoor air pollution, access to information through television and access to cell phone service (Komatsu et al., 2011; Urmee et al., 2009). These experiences indicate that SHS have the potential to address multiple SDGs and improve community resilience. Shammin et al., (2022, Chap. 2 of this volume) has developed an integrative framework for climate resilient communities that connects climate adaptation, resilience, and SDGs.



District	Branch	SHS User	Non-SHS user
Bagherhat			
	Rampal-1	47	50
	Rampal-2	28	32
	Mongla-1	40	53
	Mongla-2	34	34
	Kachua	24	25
	Chitalmari	39	39
	Kasimpur	65	60
Khulna			
	Dacope	64	61
	Batiaghata-1	89	78
	Batiaghata-2	70	68
		500	500

Fig. 14.2 Sample count and distribution of field surveys. *Source* Authors' creation based on Google Maps

Table 14.1 Key characteristics of the respondents and their families

Description	SHS users	SHS non-users	All	Significance
Female (respondent)	21.00	26.85	23.92	**
Male (respondent)	79.00	73.15	76.08	**
Married (respondent)	91.67	92.77	76.08	**
Age (respondent)	40.34	39.13	39.74	
Household size	4.88	4.70	4.79	*

Note * means 10%, ** means 5% and *** means 1% level of significance
Source Field data 2012–13

The results of this study have been organized below under primary benefits and secondary benefits with their relevance to SDGs depicted using corresponding icons. Additionally, the outcomes of SHS have been assessed based on the way they contribute to building community resilience.

14.5.1 *Primary Benefits of SHS*

More than 90% of the households sampled in this study report using kerosene lamps as their current or previous source of lighting energy (for non-SHS users and SHS users, respectively). When SHS users were asked a question about the benefits of solar power as part of this study, the majority report improvements in quality of life in terms of comfort and convenience (~ 83% of users surveyed). In addition to lights, they use mobile phones, televisions, fans and other small appliances (Fig. 14.3).

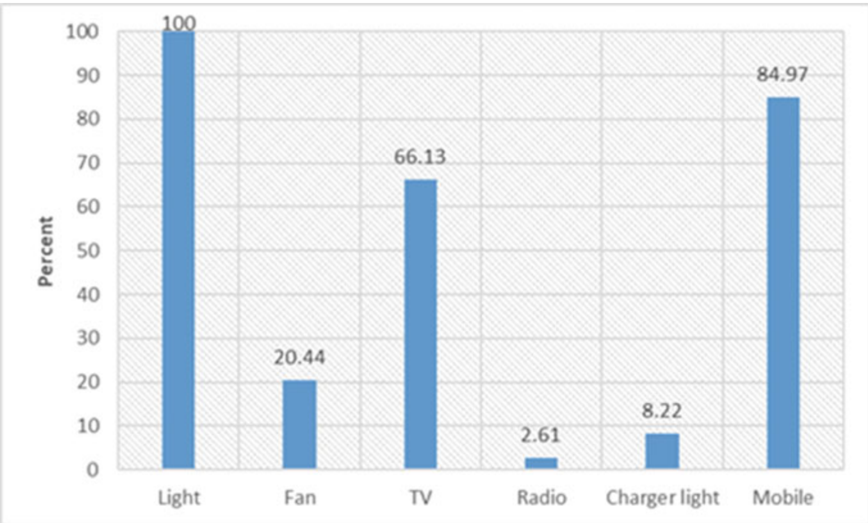


Fig. 14.3 End uses of solar power reported by SHS users (percent of households reporting use). *Source* Field data 2012–13

Lighting remains the most important use of solar power as about 70% of the SHS users mention 'insufficient light' as a major problem with their previous energy source. They report higher quality of light from solar power and ~ 25% extension of time of use of lighting source at night. Using a paired sample test, this study finds that solar users use electricity significantly longer with solar than with their previous light source (t (496) = − 19.57, $p < 0.001$). 99.4% of the users state that the solar lights are better than their previous energy sources with 91.5% characterizing the improvements as moderate to extraordinary. These are consistent with the findings by previous studies that SHS users clearly prefer the quality of light provided by the SHS compared to the kerosene lamps they used before. They like the ability to power additional equipment and also experience better night-time security (Asaduzzaman et al., 2013; Biswas, 2004; Komatsu et al, 2011; Urmee et al, 2009). Another study of two off-grid communities in Africa found that SHS reduce the use of disposable batteries (Stojanovskia et al., 2017).

Kerosene lamps produce black carbon and CO_2 during combustion that can affect the lungs, increase risks of asthma and cancer, and increase vulnerability to infectious diseases (Apple et al., 2010; Lam et al., 2012; Tedsen, 2013). If materials in lamps contain lead, this poses additional health risks (Lakshmi et al., 2013). Asaduzzaman et al. (2013) found that the incidence of several types of preventable illness such as general ailment, respiratory diseases, and gastrointestinal problems were lower among the members of the households that purchased SHS in Bangladesh. However, when non-users were asked about problems with their current source of lighting energy (e.g., kerosene), only 11% of the respondents identified air pollution from lighting as a concern and only some SHS users mentioned the pollution-free indoor environment that contributes to good health and well-being. It is possible that lack of awareness of indoor air pollution, and its impact is the reason for the limited acknowledgment of this benefit of solar lights.

This study finds that the question of affordability is more nuanced than a simple cost–benefit analysis and payback estimates. Currently, the IDCOL program receives approximately 10% of the cost through grant money. Partner organizations receive an additional, smaller percent as support for institutional development. The remaining 90% cost of the system is micro-financed by the households at interest rates between 6 and 12% with a 15% down payment. The households surveyed were charged 6% interest rate for a three-year loan—resulting in an average monthly payment of Tk. 816 which is about 4 times higher than the average monthly cost of kerosene lamps. Beyond the payment period, however, the monthly cost of solar power would be reduced to zero for the life of the panel, excluding the costs of system maintenance, troubleshooting or battery replacement. If future benefits are not discounted, the all-inclusive average monthly cost of solar power over ten years would be 282 Taka/month (for a three-year financing scheme). Results from this study show that the average cost of lighting energy from kerosene is approximately Taka 210/month. Therefore, at the very least, solar power is about 35% more expensive in the long run than their previous energy source for households who make the switch. While this may raise questions about the affordability of SHS, it should be noted that the SHS provides better quality lighting and additional benefits compared to their existing source of lighting. While we do not have data on the actual longevity of these solar panels, the typical life of solar photovoltaic (PV) panels in developed countries is 25–30 years (Solar Reviews, 2020).

When asked about maintenance issues, 80% of the users reported that they had no maintenance issues with their systems. This is primarily because the maintenance warranty was included in the cost of the systems for the duration of the loan and all households surveyed were still within that period. 91% of the users state that the community representative of the PO that installed the systems, visited them monthly to conduct inspections. During informal conversations, SHS users appeared to be comfortable with the technology and generally satisfied with the performance and maintenance of the systems. Hence, the households are spending more money, but availing of more services, with greater benefits and a reliable source of energy.

Diesel generator is another possible energy source for rural off-grid communities. Biswas et al. (2004) reported that solar electricity is significantly cheaper than small diesel generators in rural, off-grid areas in Bangladesh. This is due to the poor economy of scale at the local level for producing and distributing generators, where the low-electricity consumption is not worth the associated infrastructure costs. There are also noise pollution, air pollution, and GHG emissions associated with generators. This survey reveals that less than 5% of the non-SHS users currently use generators and less than 1% of the SHS users consider it as an alternative to solar power.

Overall, SHS deliver a clean energy source for people in rural off-grid climate vulnerable communities and ensure better indoor air quality for improved health and well-being; but their affordability remains questionable and nuanced.

Technological leapfrogging toward renewable energy has been a centerpiece of developing country participation in climate mitigation under the Paris Agreement. The GHG reduction potential of displacing kerosene lamps is known to be relatively small per household (Baurzhan & Jenkins, 2016), but the accumulated global CO_2

reductions by SHS can be significant if millions of people in developing countries adopt this technology. The SHS are thus a part of Bangladesh's national contribution to global greenhouse gas reduction goals. The 4.1 million SHS installed in Bangladesh as of early 2019 are expected to displace 3.6 million tons of kerosene over the next 15 years (IDCOL, n.d.) and prevent emission of 10 billion tons of CO_2. This translates to about 163 kg CO_2 per household per year. This appears to be a low estimate as Hoque and Das (2013) report about four times higher GHG emission reductions by SHS in Bangladesh, comparing laboratory test results of the specific type of kerosene lamps used with 50 W solar panels.

Observations made during field work also revealed interesting ways the SHS are contributing to climate change adaptation at the community level. Solar power has made cell phones accessible in these communities, in turn providing them with new tools for early warning systems and disaster response during floods, storms, and cyclones – which occur frequently in these communities due to climate change.

14.5.2 Secondary Benefits of SHS

Urmee (2009) reported new income generating activities as one of the co-benefits of SHS. This is confirmed through survey results, field observation, and anecdotal evidence from this study. Access to electricity makes better quality lighting available for longer hours for SHS users and creates opportunities for household crafts, tutoring of children, and other productive activities. More productive hours in the evening frees up time during the day to engage in farming, business, and other enterprises.

Several new business enterprizes were observed in the rural marketplaces of the communities surveyed in this study. Solar power made it possible for SHS users to have access to electronic equipment such as cell phones, radio, television, etc. To support the maintenance of this new equipment, the marketplaces now feature services for charging cell phones and repairing electronics as well as sale of voice and data packages. With cell phone access, money transfer services such as *bKash* also became accessible to these communities. While the SHS project primarily targeted households, it turned out that businesses also adopted solar power. Barber shops and convenience stores were able to use solar lights to extend their operating hours into

Fig. 14.4 Solar powered convenience store, barbershop, and electronics repair service from left to right. *Photo credit* Md Rumi Shammin

the evening. Halder (2016) found similar benefits of SHS in local small businesses in two randomly selected villages in Sirajgonj and Jessore districts in Bangladesh.

Field observations in the communities surveyed in this study illustrate creative and innovative ways of using solar power (Fig. 14.4). In one village, multiple stores were sharing one solar system. In another instance, a solar panel was installed on a box frame that could be moved around throughout the day to maximize exposure to sunlight and then stored inside the store at night for security.

About 82% of the SHS users expressed that their previous light source affected their children's education and a nationwide study found statistically significant differences in the study habits of children with solar lights. (Asaduzzaman et al., 2013).

The majority of non-users reported that their current source of light does not meet their needs. The extended use of lights by SHS users was statistically significant when compared with non-users (see Table 14.2).

Table 14.2 Differences in lighting use duration between SHS users and non-users

Hours of lighting	obs	Mean	SE	SD	Significance
Prior to SHS connection	497	3.97	0.041	0.923	
After SHS connection	497	4.83	0.041	0.906	
Full sample	994	4.40	0.032	1.009	
Difference in mean		-0.85	0.058	-0.967	***

Note *** significance at 1% level
Source Field data 2012–13

Table 14.2 indicates that after SHS connections, households increased their total hours of lighting by nearly an hour (0.85 * 60 = 51 min). The increase is statistically significant, and it can be argued that their standard of living increased due to the solar home systems. Since it is the women who do the chores every day, ease of lighting or convenience meant that it is women who enjoyed the benefits. It probably provided them with some extra time to do other things of their choice or enjoy the time in leisure.

Anecdotal evidence documented during field surveys reveals specific ways SHS are empowering women. Salma,[2] a high school educated divorced self-employed woman, reported a doubling of her household income from tutoring children after hours. She described how having more productive hours in the evening freed up time during the day for her to engage in other income generating activities. She also indicated how better lighting in the kitchen reduces the risk of cooking related accidents (e.g., fire hazards). This is consistent with findings by Asaduzzaman et al. (2013) that women are directly impacted by SHS by having access to the longer study time for their children and better lighting for cooking at night, while maintaining the nutritional quality of food. While this study did not investigate the impact of SHS on women's health, a study from India found that the health of women improved after replacing kerosene lamps with lighting powered by SHS – evidenced by reduced incidences of issues such as eye problems, headache, and coughing (Barman et al., 2017).

Equitable distribution of development opportunities is a key component of ensuring a just and sustainable future. The role of SHS in this regard can be investigated at multiple scales: community, national, and international.

At the community level, this study finds several key differences in household demographics between the randomly surveyed SHS users and non-users from the same communities. First, the household income of SHS users is significantly higher than non-users ($F = 41.05$, $p < 0.001$). Second, there is a significant gap in the level of education between SHS users and non-users ($F = 50.22$, $p < 0.001$). As evident in Table 14.1, about 57% of the non-SHS users in the sample have no education or just elementary education, whereas about 61% of the SHS users in the sample have at least middle/high school education (in Bangladesh, middle school and high school are not separately distinguished beyond fifth grade). Third, significant differences were found in the occupation between SHS users and non-users (Pearson Chi square

[2] Real name has not been reported in order to maintain confidentiality.

Table 14.3 Differences in household income, level of education and nature of occupation between SHS users and non-users

	Mean	SE	SD	Significance
Monthly income				
SHS users	8078.067	198.977	4449.260	
SHS non-users	6477.567	151.036	3377.256	
Differences in mean	– 1600.500	249.807	– 2090.707	***
Highest level of family Education				
SHS users	3.706	0.079	1.755	
SHS non-users	3.190	0.080	1.781	
Differences in mean	– 0.516	0.112	– 0.735	***

Source Field data 2012–13

(5) = 78.46, $p < 0.001$). Head of households that adopted the SHS were more likely to be businesspersons, government workers, or non-governmental workers, while those who did not are more likely to be engaged in daily labor, farming, or fisheries. Both SHS users and non-users were asked about their perception of who benefits and who are left behind from the SHS initiatives in their communities. The results indicated are consistent with inferences made from the statistical analysis presented in Table 14.3 that SHS technology favors professionals, shop owners, and the more affluent (middle and high income) households.

Table 14.3 reveals that the much talked about SHS program missed the poorest strata in the society. Differences in income and education between users and non-users are statistically significant at 1% level of significance. One reason for this exclusion is that the 15% down payment and monthly installments for the microfinance loan are cost prohibitive for lower-income households as discussed below.

When asked about the barriers to access SHS, 63% of the non-users indicate cost as the main factor that prevented them from adopting this technology. Since the cost of the SHS is considerably higher than current energy sources for non-users in the short run, those who are willing and able to pay for the additional services provided by solar power become adopters. Mondal (2010) argues that in such cases, the social and environmental benefits of SHS need to be internalized into their financing metrics by leveraging national and international initiatives to improve accessibility and make the implementation of this technology more equitable.

At the national level, governments in developing countries with an obligation to bring electric power to all residents are faced with particular challenges when it comes to rural off-grid communities often located in climate vulnerable areas. Three aspects of the rural households are noteworthy: (1) they are generally more widely dispersed over the landscape; (2) they are often located in remote areas sometimes separated by a river or other natural barrier from their nearest electricity grid; and (3) they have very low-power needs per household. These aspects make it difficult and expensive to expand the existing electricity grid to incorporate them. To do so would require elaborate infrastructural additions such as power stations, substations, long transmission lines across unfavorable terrains, etc. (Komatsu et al., 2011; Zerriffi, 2011). Pode (2013) argues that due to the remoteness, isolation, low-electricity demands, and high-investment costs of grid expansion, these communities are unlikely to be reached by simply extending the power grid. These villages are therefore ideal for small-scale, distributed power solutions that deliver electricity in a convenient and cost-effective manner. SHS provide clean energy access to previously underserved communities, reduce inequalities on the national scale and advance social and environmental justice efforts where implemented.

At the international level, SHS are making a positive contribution to climate change mitigation and should receive financial assistance from international climate change funds to reduce costs and improve access. This would be ethically just given that these communities have historically contributed very little toward climate change and yet find themselves more vulnerable to the impacts of climate due to their low-lying coastal locations. Even though international agencies are featured as partners in IDCOL's SHS program in Bangladesh, most of the costs are borne by the end users through micro-credit programs. Figure 14.5 illustrates that the total value of external grants per system is less than the interest paid by the average SHS users on their micro loan and constitutes about 12% of the final cost to consumers.

A fair and equitable measure would be to leverage the international climate funds earmarked for developing countries under the Paris Agreement and find creative ways to participate in international carbon markets to generate additional foreign aid alongside earnings. IDCOL has already recognized that the avoided GHG emissions of SHS is a global commodity and is working with the World Bank to participate in the global carbon market (Asaduzzaman et al., 2013). The international community can thus play an important role in expanding the deployment of SHS and make them more

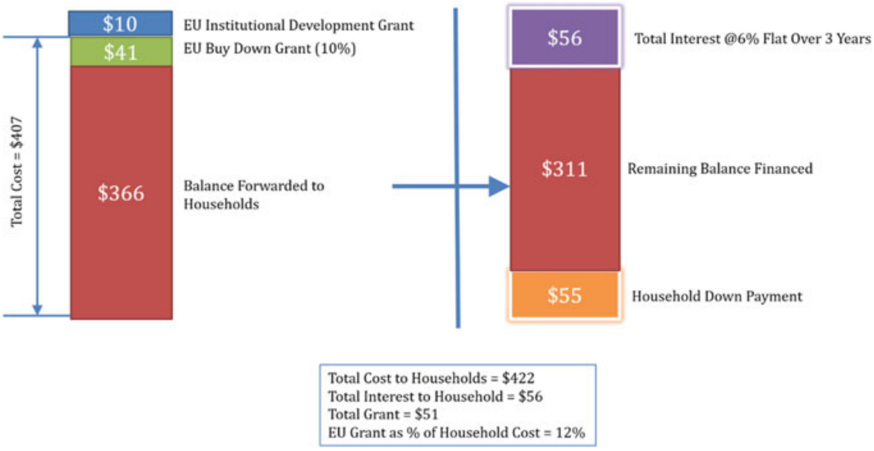


Fig. 14.5 Distribution of cost, funding, and financing of a 50-W SHS. *Note* Conversion rate used: 1 US Dollar = 80 Taka. *Source* Authors' creation based on information from IDCOL and POs

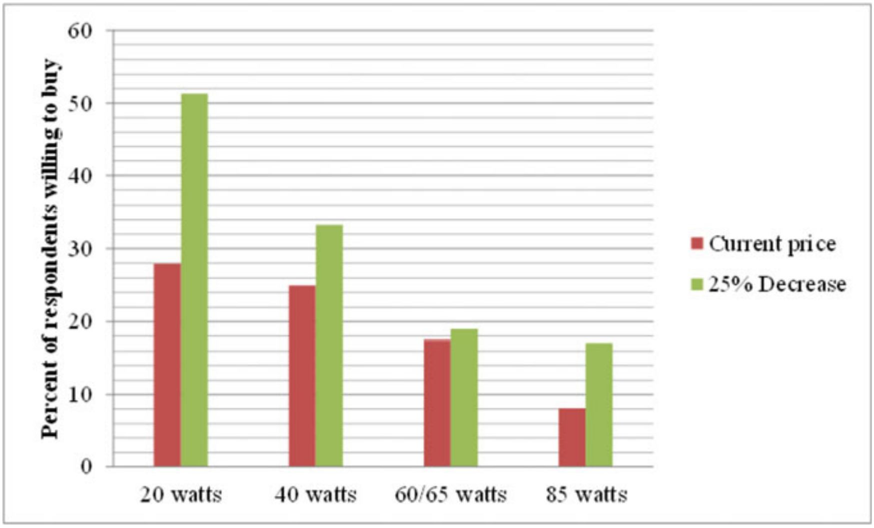


Fig. 14.6 Willingness to purchase SHS systems of different capacities under different price scenarios by households without solar power. *Source* Field data 2012–13

accessible and equitable (Chaureya & Kandpal, 2009). When non-SHS users were randomly asked about their willingness to buy solar systems of various capacities under different price scenarios, the results show that there is significant additional demand for solar systems in the communities surveyed under all price scenarios. Specifically, a 25% decrease in price and expanding distribution of smaller panels (20 and 40 W) have the potential for significantly increasing the number of SHS users (see Fig. 14.6).

Despite the uncertainties due to past political shifts in the US and the ongoing Covid-19 pandemic, any financial assistance that might still be available through international climate funds can reduce the cost of the SHS. This will make the system more affordable and lessen the financial burden of current SHS users and allow additional disposable income for them to improve their economic well-being.

14.6 Emerging Solar Solutions

While SHS remain the flagship solar project in Bangladesh, several other emerging technologies and models have been initiated by government, non-government and private initiatives in recent years. In addition to traditional rooftop solar systems, IDCOL has started two other solar projects for off-grid communities in Bangladesh: Solar irrigation and solar mini-grids. The solar irrigation project aims to install 50,000 solar PV-based irrigation pumps by 2025 in areas with three annual cropping seasons. With support from the World Bank and several other international aid agencies, over

Fig. 14.7 SOLshare grid in a marketplace in Bangladesh. *Photo credit* SOLshare

1300 pumps went into operation by fall 2019. Solar mini-grid projects are intended to provide grid quality electricity to households and small commercial users. Seven PV-based mini-grids are already operational and serve about 5000 rural households (IDCOL, n.d.). Both projects compliment the SHS project.

Another interesting private market-based initiative is SOLshare—a new approach to expand affordable solar electricity accessibility using smart peer-to-peer grids (Fig. 14.7). SOLshare has developed a marketplace called SOL bazaar, a trading platform which enables people to trade the excess solar energy generated by SHS. SHS users can sell their excess energy to non-SHS-users. This creates a win–win solution where SHS users have additional income generation opportunities and the buyer gets access to electricity (SOLshare, n.d.).

There is ongoing research and development in the design and delivery of the SHS. Zubi et al. (2019) proposed a modified layout of the SHS that integrates a lithium-ion battery-pack and is complemented with LED lamps and an energy efficient multi-cooker. Coupled with creative financing mechanisms, they hope to accomplish a more efficient and affordable alternative to the current system. Similarly, the design of LED lamps using solar-based batteries (like the NiCd, NiMH, Lithium-ion, or Lithium Polymer batteries typically used in mobile phones) instead of using lead acid batteries is also a major game changer in the uptake of SHS across the world.

14.7 Resilient Communities that Run on Sunshine

SHS deliver significant benefits to rural off-grid populations in developing countries and contribute to improving the quality of life for some of the poorest and most marginalized people in the world. This study focuses specifically on the interactions between SHS, climate mitigation, and community resilience by focusing on remote off-grid climate vulnerable communities in Bangladesh. The life cycle analysis of upstream and downstream GHG emissions from solar PV systems is similar to that of other renewables and nuclear energy, and ten times lower than coal (NREL, 2012).

SHS have the potential for delivering outcomes related to multiple SDGs. In addition to providing clean renewable energy and achieving climate mitigation, these systems create economic opportunities, empower women, advance children's education and improve living environment. While the technology appears to be reliable and user-friendly, the system remains cost prohibitive for low-income households—particularly farmers, fishermen, and landless day-laborers. These barriers may be removed by lowering the cost of the systems and running more targeted awareness campaigns. Revenues from international climate funds and carbon markets, if used to reduce the price of SHS, will increase access to this technology by aiding households who are currently left behind. Proactive initiatives that explicitly connect SHS and other solar solutions with SDGs at early stages of program development have the potential for greater attainment of the goals. This will make the use of development aid and climate financing more coordinated and efficient.

This study also reveals that solar solutions have the potential to advance community resilience. Hopkins (2009) identified modularity and tightness of feedback as two important properties of resilient systems. The SHS are distributed and modular and hence immune to a whole-system failure in case any individual unit malfunctions. They are not subject to supply disruptions of kerosene or diesel—allowing individual households to retain their energy access when communication routes are cut-off during natural disasters such as floods or cyclones. The SHS are local sources of energy, and their maintenance is also serviced by a trained local workforce. Hence, the feedback loop between the systems and their end-use is short, transparent, and accessible. Additionally, access to cell phones during natural disasters facilitates quick dissemination of early warning systems and coordination during disaster response. Cell phones also provide access to communication technology during other emergencies (e.g., medical). Bangladesh has nationwide coverage of internet data service which is now available to these communities—thus opening up access to global databases of knowledge and information. Since these are climate vulnerable communities, new enterprises made possible by solar solutions provide alternate economic opportunities for farmers and fishermen whose livelihood might be threatened by climate change—thus reducing the risk of displacement and climate migration.

Finally, the study of SHS demonstrates how solar solutions offer communities the ability to take ownership of and participate in climate change mitigation and adaptation. They allow for technological penetration without technological imperialism. However, the most important point to note is that some of the poorest and most marginalized populations in the world are participating in a carbon-free energy future, while many developed countries are yet to act boldly. As long as the sun shines, communities across the developing world can use the power of the sun to survive the wrath of the rising seas and roaring skies—striving toward a just, equitable, sustainable, and resilient future.

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