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Are micro-benefits negligible? The implications of the rapid expansion of Solar Home Systems (SHS) in rural Bangladesh for sustainable development

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ABSTRACT

This paper examines the multiple benefits of the adoption of Solar Home Systems (SHS) and discusses the dissemination potential for sustainable rural livelihoods in developing countries. Based on a household survey conducted in rural Bangladesh, we first identify the impact of SHS on the reduction in energy costs and compare purchasing costs. We then examine household lifestyle changes following the adoption of SHS. Finally, we consider several price-reduction scenarios to examine the potential demand for SHS and to evaluate its future dissemination potential. The results of the analysis indicate that households with SHS successfully reduce their consumption of kerosene and dependency on rechargeable batteries, with the cost reductions accounting for some 20–30% of monthly expenditures on SHS. Moreover, most households with SHS can enjoy its benefits, including electric lighting, watching television, and the ease of mobile phone recharging at home. Further, the price reduction can make possible potential demand in more than 60% of households without SHS, while additional price reductions promote the purchase of even larger SHS packages. This study concludes that even though the scale of single SHS is small, the micro-benefits for each household and the dissemination potential are substantial.

1. Introduction

Currently, 1.456 billion people worldwide suffer a deprived supply of electricity, of which 99.8% live in developing countries (IEA, 2009). However, although electricity is a necessity for improving the livelihood of rural households, grid expansion often requires expensive financial investment in infrastructure (power stations, substations, transmission lines, etc.), such as in a developing country like Bangladesh. Grid expansion also implies an increased dependence on fossil fuels and incremental emissions of greenhouse gases (GHG). Accordingly, Solar Home Systems (SHS) based on solar photovoltaic (PV) systems for individual households are becoming more popular in non-electrified areas of developing countries as an affordable alternative for obtaining access to electricity. Unfortunately, the amount of sunshine combined with the relatively small size of SHS at the household level effectively limit electricity generating capacity. Accordingly, as the production of electricity is typically in the range 30–130 Watt peak (Wp), SHS would normally allow households to use only low-powered electrical devices such as electric lamps, radios and cassette players, (black and white) televisions (TV), and mobile phone rechargers.

Worldwide solar PV installation for off-grid regions increased up until 2008 (REN21, 2009). SHS projects have also steadily expanded in the developing countries of Asia, South America, and Africa in the last thirty years, especially after the 1990s, with the installation of some 931,700 SHS units in developing countries up until 2000 (Nieuwenhout et al., 2001). While recent figures on the number of SHS units in developing countries are not available, we would expect that the number of installations has continued to increase rapidly as the use of SHS becomes a popular electrification method in developing countries. For example, the rapid growth of demand for SHS can be readily observed in Sri Lanka (Wijayatunga and Attalage, 2005), India (REN21, 2009), and Bangladesh (IDCOL, 2010).

The rewards for households with SHS comprise two kinds of benefits, namely savings in energy costs and improvements in lifestyle. First, the installation of SHS can reduce the costs of fuel such as kerosene and paraffin, and allow the removal of the rechargeable batteries relied upon before the installation of SHS (e.g., Wijayatunga and Attalage, 2005; Mondal, 2010). Second, the contribution of SHS in rural households is also extensive in terms of convenience, improvement in the quality of life, safety, and better quality of lighting from electric as opposed to kerosene lamps (e.g., Martinot et al., 2001; Urmee et al., 2009).

That said, even though the costs of rural electrification with SHS are lower than those of grid expansion, high investment costs for the poor in developing countries usually characterise SHS projects. For instance, a 50-Wp system costs US$490–500 in India and

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US$480 in Sri Lanka, whereas a 40-Wp system could cost up to US$500 in Vietnam or Cambodia (Urmee and Harries, 2009). 50-Wp systems in Bangladesh cost about US$408 (Grameen Shakti, 2009a). Importantly, households wishing to install SHS must be able to cover most of the upfront cost, irrespective of the nature of the financial support available from donors or non-governmental organisations (NGOs) in the form of loans or grants.

On the supply side, there is the prospect of reducing the price of PV modules through reductions in the cost of equipment (van der Zwaan and Rabl, 2004; Albrecht, 2007). Moreover, the global PV market grows at 30% every year, and this will encourage cost reductions in PV modules (Albrecht, 2007). In fact, the market price of PV modules has been falling over the past twenty years, with prices decreasing at 20% per annum (per Wp) from 1976 to 1996 (van der Zwaan and Rabl, 2004). These evolutional trends will encourage price reductions in SHS. As SHS packages consist of other components, such as batteries and electric lights, in addition to the administrative costs, there will be further potential for price reductions in the future.

A question that arises in the context of the promotion of SHS-based rural electrification is whether households that purchase SHS can enjoy tangible benefits commensurate with the high cost of installation. Another question concerns whether it would be possible to boost the demand for SHS through reducing the price of the equipment. As a way forward, this study attempts to estimate the impact of SHS on energy cost reduction by comparing the expenditure on energy with the payments on SHS. If households with SHS can gain substantial benefits, even with the small-scale SHS currently available, the micro-benefits will have a considerable impact on rural society through the increasing use of SHS.

The main contributions of this paper are twofold. First, we identify the impact of SHS on the reduction in energy costs, and compare the purchasing costs of SHS. We examine the impact on energy cost reduction by comparing the expenditure on energy with the payments on SHS. If SHS can become a sufficient alternative energy source for the household, then the cost reduction impacts may be enormous. To date, few studies have analysed these cost reduction impacts numerically, with the exception of Wijayatunga and Attalage (2005), who showed that in Sri Lanka expenditure on kerosene decreased to zero for more than 90% of households following installation of SHS. Moreover, earlier studies evaluate the effects of lifestyle changes with a "before and after comparison" (e.g., Acker and Kammen, 1996; Gustavsson and Ellegård, 2004; Urmee and Harries, 2009; Linguet and Hidair, 2010). A comparison between SHS households and non-SHS households should also provide additional insights into the impact of SHS adoption on the standard of living, hitherto limited to work by Wamukonya and Davis (2001). Second, we examine the dissemination potential of SHS for households without SHS given the price reduction. Unlike the previous literature, we need to assess the potential demand for SHS from the viewpoint of potential users. To do this, our analysis provides some scenarios for SHS price reductions, and obtains the latent demand for SHS of households currently without SHS.

This study examines the benefits of adopting SHS and the future dissemination potential of SHS using a household survey conducted in 2009 in rural Bangladesh, a country where rural electrification with SHS has proceeded rapidly. The structure of the paper is as follows. Section 2 describes solar photovoltaics and the diffusion of SHS. Section 3 summarises the case activities of the three regions that field survey conducted for both families with and without SHS. Section 4 details the impact on energy cost reduction and then compares these benefits with the payments associated with the adoption of SHS. Section 5 discusses the lifestyle changes in the households from the viewpoint of the benefits of electric lighting, watching television, and mobile phone recharging. Section 6 illustrates the impact of the declining prices of SHS on the further diffusion of SHS for households currently without SHS. The final section concludes.

2. Solar photovoltaics (PV) in Bangladesh

Bangladesh has a low electrification rate, in that only 28% of rural households have access to electricity (IEA, 2009). However, while there is an urgent need to expand rural electrification to improve the standard of living in rural Bangladesh, the electricity sector suffers from acute problems in terms of insufficient power generation capacity and a lack of distribution infrastructure. About 88.8% of the country's electricity generation currently draws on domestic natural gas (Bangladesh Bureau of Statistics, 2009). However, Bangladesh's domestic gas reserves may be exhausted in the near future. In order to increase electricity demand in accordance with the rapid economic growth of the country, some 6.2% per year in 2008 according to the World Bank (2010), the Bangladeshi government is urgently required to improve the electricity supply. In this context, the high upfront cost of expansion of the national grid to isolated and rural areas is an impediment to extending the supply of grid-based electricity to additional rural areas.

Promotion of decentralised electrification based on renewable energy, especially solar PV systems, can be an effective alternative for supplying electricity to off-grid regions in Bangladesh. According to the Renewable Energy Policy of Bangladesh, published in 2008, renewable energy is recognised as having a strong potential for delivering electricity services to the entire country by the year 2020 (Government of the People's Republic of Bangladesh, 2008). Islam et al. (2006) comprehensively reviewed the potential of renewable energy and identified solar PV systems as the most effective electrification option from a resource availability perspective relative to wind or hydropower generation in Bangladesh. In addition, several studies have investigated the benefits of using solar PV systems in Bangladesh, including Biswas et al. (2001), Barua (2001), Wamukonya (2007), and Urmee et al. (2009). Solar PV is also considered the most viable option for electrifying rural households, with estimates suggesting there were some 645,033 SHS installed in Bangladesh to August 2010 (IDCOL, 2010).

This research was conducted at a site where Grameen Shakti is actively working to install SHS at the household level in Bangladesh. Grameen Shakti, an NGO and member of the Grameen Bank group, was established in June 1996 to specialise in the promotion of renewable energy in Bangladesh (Barua et al., 2001). Grameen Shakti's main activity is the solar PV program, and it had already installed 317,591 SHS units by 2009 (Grameen Shakti, 2009b). Fig. 1 depicts the diffusion speed of SHS until 2009, clearly showing that yearly installation has increased sharply, with a 50% increase in installations from 2008 to 2009 alone. To implement the program, Grameen Shakti selected remote areas without a conventional electricity supply and no chance of connection to the electricity grid in the next 5–10 years (Barua, 2001).

As shown in Table 1, Grameen Shakti sells a number of SHS packages under several different payment options. Typically, customers pay 15–25% of the total price of the package as a down payment, with the balance being paid off over a two- or three-year repayment period subject to a low interest rate (6–8%). Households may also pay the total price of the package chosen at once to obtain a 4% discount, but few households select this option.

3. Survey design[1]

Fig. 2 maps the surveyed districts, namely Comilla, Kishoreganj, and Manikganj. A door-to-door household survey was conducted in

[1] A summary of the survey design is provided in Komatsu et al. (unpublished).

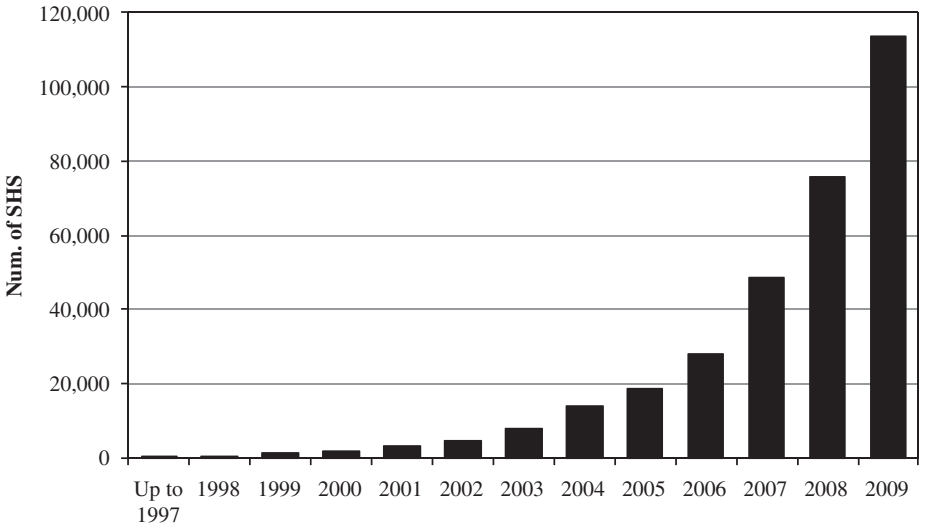

Fig. 1. Yearly installation of SHS.
Source: Grameen Shakti (2009b).

Table 1
Sizes of SHS and components of package (as of January 2009).
Source: Grameen Shakti (2009a). The exchange rate is from the Bangladesh Bureau of Statistics (2009).

Capacity	Home appliances	Other components	Total price
40 Wp	Three lights, each 6 W capacity	One 40 Wp solar panel One 55 Ah industrial battery	22,500 taka (US$328)
50 Wp	Four lights, each 6 W capacity	One 50 Wp solar panel One 80 Ah industrial battery	28,000 taka (US$408)
65 Wp	Six lights, each 6 W capacity	One 65 Wp solar panel One 100 Ah industrial battery	34,000 taka (US$496)
85 Wp	Seven lights, each 6 W capacity	One 85 Wp solar panel One 130 Ah industrial battery	42,500 taka (US$620)
120 Wp	10 lights, each 6 W capacity	One 120 Wp solar panel Two 100 Ah industrial batteries	65,000 taka (US$948)
130 Wp	11 lights, each 6 W capacity	One 130 Wp solar panel Two 100 Ah industrial batteries	68,000 taka (US$991)

Note: This price list is applicable for rural areas only. For each package, a charge controller and other accessories are included.
While contracts for 10 and 20 Wp are included in the price list, we omit them because no households chose those contracts according to the survey.
US$1 was equivalent to 68.60 taka in 2007–2008.

selected sub-districts in each district. The surveyed sub-district in Manikganj is approximately 20–30 kilometres (km) to the north-west of Dhaka, the capital of Bangladesh, whereas those in the Kishoreganj and Comilla districts are approximately 80 km from Dhaka.

Table 2 provides socio-demographic information on the three survey districts. There are several similarities and disparities among these districts. In all three districts, more than half of the population is employed in agriculture. In contrast, there are slight differences in the electrification ratio, with 31.28% in the Singair sub-district of Manikganj, 35.33% in the Muradnagar sub-district of Comilla, and a slightly lower 8.70–26.86% in the sub-districts of Kishoreganj. Economic indicators such as regional GDP in each district could not be obtained from the statistical yearbook of Bangladesh.

At the district level, Comilla is relatively less dependent on agriculture, and the level of poverty is less severe than in the other two districts. The proportion of households whose main income source is agriculture is 58.32% in Kishoreganj, 54.08% in Manikganj, and somewhat lower at 40.03% in Comilla (Bangladesh Bureau of Statistics, 2006a, 2006b, 2007). According to the poverty headcount ratio index, Comilla is characterised as having the lowest poverty ratio among the three districts (30.1–35%), then Kishoreganj (40.1–45%), and finally Manikganj (45.1–50%) (UNDP Bangladesh, 2000).[2] The targeted respondents in the survey include both households with SHS (hereafter abbreviated to "SHS households") and those without SHS (hereafter "non-SHS households"). Households in both categories have no access to electricity from the grid.[3]

A pilot survey was conducted in Tangail district in March 2009, the area where Grameen Shakti initiated its activities. The results of this survey were used to obtain basic information on perceptions and opinions about solar PV systems, SHS packages, access to energy and standards of living, including the income of the SHS households. The respondents were mainly the household decision makers, either the household head or the spouse of the household head. As the literacy rate is very low in rural Bangladesh, skilled field surveyors were hired to administer the survey in a face-to-face interview with each respondent. The surveyors received training

[2] The exact value of the poverty headcount ratio is not included in UNDP Bangladesh (2000).
[3] Two respondents use both SHS and electricity from the grid. Because these are unique cases, we exclude them from the sample.

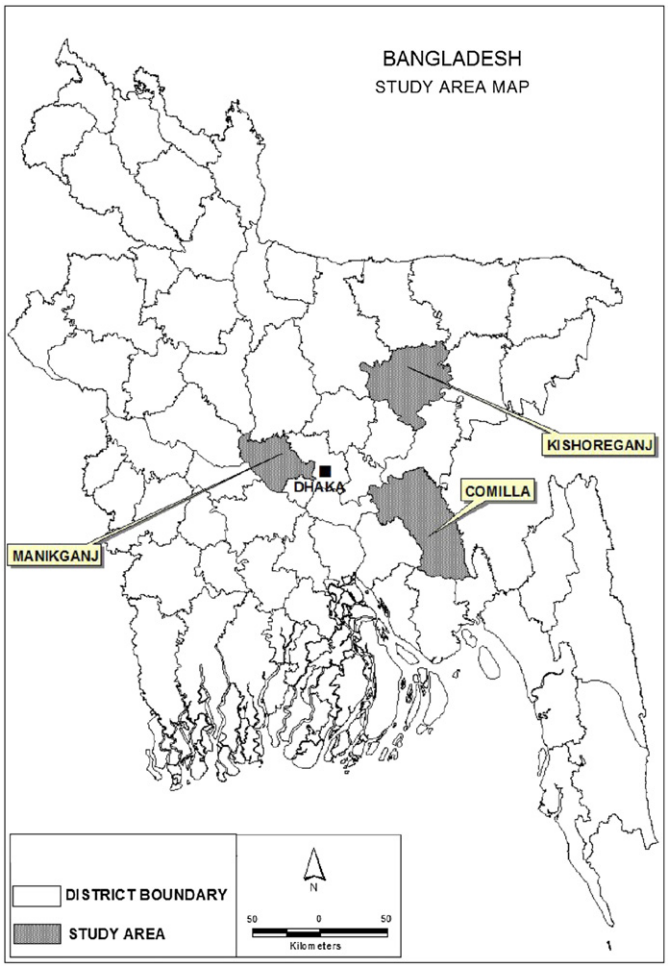

Fig. 2. Study area map.

Table 2
Demographic information for surveyed districts.
Source: Bangladesh Bureau of Statistics (2006a, 2006b, 2007).

	Manikganj	Kishoreganj	Comilla
Total area (km^2)	221.45	531.13	339.00
Number of households	51,778	157,473	83,769
Population	248,615	760,313	468,080
Proportion of households whose main income source is agriculture (%)	58.39	52.74–72.56	51.15
Electrification ratio (%)	31.28	8.70–26.86	35.33

Note: All the indicators refer to the surveyed sub-districts (Singair sub-district in Manikganj, three sub-districts (Kishoreganj Sadar, Karimganj, and Tarail) in Kishoreganj, Muradnagar sub-district in Comilla). Because the number of families that installed SHS is relatively small, three sub-districts were selected in Kishoreganj district, namely Kishoreganj Sadar sub-district, Karimganj sub-district, and Tarail sub-district in order to ensure a sufficient number of respondents and to make the survey efficient.

before the pilot survey was conducted in order to ensure that they clearly understood the survey design.

The main survey was conducted in August 2009. A total of 304 households (102 from Manikganj, 101 from Kishoreganj, 101 from Comilla) were included in the survey of SHS households, and another 308 households (103 from Manikganj, 102 from Kishoreganj, 103 from Comilla) were included in the survey of non-SHS households.

Table 3 shows the number of SHS installations during 2002–2008, and Table 4 presents the number of SHS by installed

Table 3
Yearly installations of SHS by location.

Districts	Unit: Number of households						
	2002	2003	2004	2005	2006	2007	2008
Manikganj	0	1	1	14	10	36	40
Kishoreganj	0	0	2	0	24	30	45
Comilla	6	7	7	12	10	21	38

Table 4
Number of households with SHS units by installed capacity.

Districts	Unit: Number of households					
	40 Wp	50 Wp	65 Wp	85 Wp	130 Wp	Other
Manikganj	16	39	32	9	0	6
Kishoreganj	32	53	13	3	0	0
Comilla	29	52	12	2	1	5

Note: "Others" category includes SHS of 60 or 75 Wp etc. that are not currently available.

capacity in the three districts. Table 3 indicates that most households have only adopted SHS recently, especially from 2005. This trend corresponds to the dissemination speed of SHS implemented by Grameen Shakti, as shown in Fig. 1. Table 4 shows that the most popular SHS sizes were 40, 50, and 65 Wp, with a possible motivation being that the prices for these packages appear to be relatively more affordable.

4. Benefits of reducing energy costs through installing SHS

As SHS provide alternative electricity for households, households can change their source of electricity from kerosene and rechargeable batteries to SHS. To verify the numerical impact of the source of electricity, this section discusses the consequences of fuel cost reduction in terms of kerosene and rechargeable batteries with SHS adoption.

4.1. Reduction of kerosene consumption

Kerosene is a common fuel for rural households in Bangladesh. Households generally use it for lighting at night and for the cooking stove in the kitchen. Table 5 details the number of households that use (or used) kerosene lamps, and the average amount of kerosene consumption per household. The table shows that all of the SHS households used kerosene before installing SHS. Around half of SHS households stopped using kerosene lamps after purchasing SHS, and kerosene consumption by current kerosene users has dramatically decreased. However, kerosene consumption has not fallen to zero, because households sometimes use kerosene lamps when SHS lighting is insufficient for illumination. Nonetheless, there are slight disparities in the dependency on kerosene lamps following the installation of SHS, in that the owners of larger capacity SHS packages are relatively free from kerosene lamps. This result appears to reflect the number of electric lights available in each package, with the larger packages having a greater number of electric lights.

Currently, all the non-SHS households (308 households in total) use kerosene lamps, and the average kerosene consumption is calculated as 3.36 l per month. The average consumption of SHS households before SHS installation is higher than the current consumption of non-SHS households, but Table 5 confirms that

Table 5
Change in kerosene consumption.

	Total number of SHS households	Number of SHS households that use (or used) kerosene lamps		Average amount of kerosene consumption per household (litres/month)	
		Before	Now	Before	Now
40 Wp (n=77)	77	77	44	3.49 (n=77)	0.86 (n=44)
50 Wp (n=144)	144	144	75	4.09 (n=144)	0.93 (n=75)
65 Wp (n=57)	57	57	18	4.03 (n=57)	0.72 (n=18)
85 Wp (n=14)	14	14	4	4.39 (n=14)	1.69 (n=4)
Others (n=12)	12	10	4	3.83 (n=12)[a]	1.69 (n=4)

[a] Two households reported using kerosene before installing SHS, but did not use a kerosene lamp.

Table 6
Change in the use of rechargeable batteries.

	Before	Now
40 Wp (n=77)	35	0
50 Wp (n=144)	78	3
65 Wp (n=57)	26	1
85 Wp (n=14)	5	1
Others (n=12)	5	0

households with a heavy consumption of kerosene were successful in decreasing their dependence on kerosene after installing SHS.

There are significant positive impacts on the environment at home through the decrease in kerosene use, because kerosene use results in serious indoor pollution. In Ghana, Obeng et al. (2008) found that the risk of indoor pollution could be significantly reduced by SHS, because they allowed households to replace kerosene lamps with electric lamps. This result confirms that a reduction of kerosene consumption encourages SHS households to create better air quality at home.

4.2. Abolishment of rechargeable batteries

Rechargeable batteries are quite popular electrical devices in rural Bangladesh, and typically comprise grid-charged car batteries (Mondal, 2010). These can store electricity and be recharged multiple times, and households use these batteries for watching (black and white) TV, recharging mobile phones, and operating other low-load electrical devices. To recharge the batteries, household members are required to carry them to recharge stations at marketplaces, which is quite burdensome. Rechargeable batteries are usually very heavy to carry, and incur transportation costs along with the costs of recharging.

As shown in Table 6, of 304 SHS households in the sample, 149 households possessed rechargeable batteries before the installation of SHS. However, only five households retained these batteries after SHS installation. Conversely, of the 308 non-SHS households, 50 households retained rechargeable batteries. Before installing SHS, SHS households charged their rechargeable batteries about 2.05 times per month, and it took 2.03 days to recharge the batteries fully. As almost none of the households use rechargeable batteries now, they are free from these burdens.

4.3. Impact of energy cost savings

To assess the monetary benefits of energy cost savings, this subsection compares the amount of saved energy with the expenditure on SHS. The households with SHS need to pay the cost of SHS with monthly repayments; at the same time, they can alleviate their expenditure because their energy costs will decrease. To verify the amount of energy cost savings, we first examine the kerosene cost reduction and the abolishment of rechargeable batteries. The reduction in energy costs themselves and transportation costs are discussed separately, because sometimes households use facilities such as rickshaw or carts for transportation, because these sources of energy, especially rechargeable batteries, are heavy to carry. We then consider the monthly expenditures on SHS. In this regard, households need to make the monthly payments specified in the contract, as well as the cost of repairs that are not covered by the warranty scheme. We assume expenditure on the repair of batteries is zero if batteries are repaired under the warranty. Table 7 summarises the components examined. For analysing the fuel cost reduction during the repayment periods, the comparison was limited to SHS households only paying a monthly fee at the time of the main survey (September 2009). Given that the commodity value of travel time can be accounted for by the discounted value of the wage rate (e.g., Chavas et al., 1989), even though the transportation facilities are not in use, this research does not account for the costs of travel time, because the appropriate wage rate determined by markets in rural Bangladesh was not available.

Fig. 3 provides the results of the comparison. The left-hand bar in each package indicates the monthly payments for SHS in addition to the expenditure on the repair of batteries. It can be seen that almost all of the expenditure is on monthly payments for the SHS. The right-hand bar indicates the energy cost savings for each household. The majority of energy cost reduction comes from reduced kerosene consumption, followed by reduced transportation costs of rechargeable batteries.

Surprisingly the transportation costs of rechargeable batteries are higher than the charging costs, which reflect the weight of the batteries. Irrespective of the wattage that the SHS household uses, the energy cost savings are approximately 200–300 taka per month per household. As the kerosene consumption of a large package holder was previously higher, the reduction in kerosene costs is larger. However, the results reveal that even households with the smaller packages can achieve energy cost savings. The results also confirm that monthly expenditure appears to be high, but after accounting for the fuel cost reduction, households can alleviate their burden of energy-related expenditures.

5. Non-monetary lifestyle benefits

The benefits that SHS households enjoy are not limited to the reduction in energy costs. Households can also enjoy non-monetary benefits of SHS, which we observe as a lifestyle change. This section summarises the benefits for the households in terms of the use of electric lights, watching television, and the use of mobile phones.

Table 7
Comparison of the monthly expenditure on SHS and fuel cost reduction.

Energy cost savings	Kerosene	Energy cost	Decrease in expenditure on kerosene
		Transportation cost	Decrease in the transportation cost for kerosene (fee for rickshaw cart, etc.)
	Rechargeable batteries	Energy cost	Decrease in expenditure on charging rechargeable batteries[a]
		Transportation cost	Decrease in the transportation cost for rechargeable batteries (fee for rickshaw cart, etc.)
Monthly expenditure on SHS	Monthly repayments for SHS		
	Expenditure on the repair of batteries (calculated by the frequency of repair and the expenditure needed for each repair)[b]		

[a] We assume the benefits for those that continue to use rechargeable batteries after purchasing SHS are zero.
[b] The SHS users also noted problems with the charge controllers, but these are frequently repaired at no charge. We have no information on any breakdowns in the solar panels.

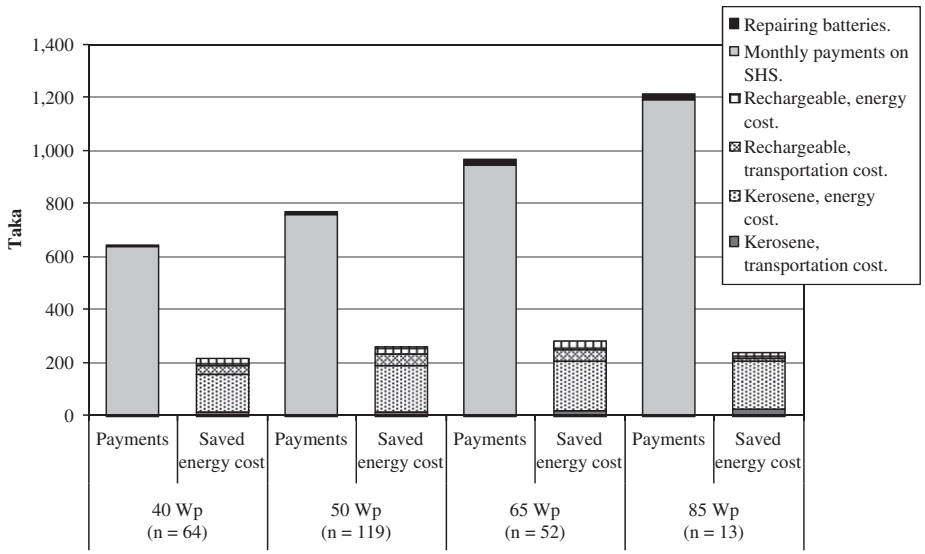

Fig. 3. Comparison of the monthly payments on SHS and the saved amounts of energy. *Note*: All price indicators are 2008 prices adjusted by the annual average consumer price index (IMF, 2009).

5.1. Benefits of using electric lights

Use of electric lights is the primarily benefit, and the larger the SHS package, the more electric lights are available for the household. Fig. 4 describes the benefits of using electric lights for each SHS household. With all SHS packages, households mention the benefits of the extension of study time for children, and working until late at night. Many households who indicate the extension of study time for children advise that their children studied until 8–9 pm before SHS adoption, but extended this until 10–11 pm following the introduction of SHS. Moreover, households worked until 8–10 pm before installing SHS, but extended this until 10–12 pm afterwards.

In addition, electric lamps provide a better quality of lighting, which not only improves the indoor air quality but also creates a better environment for studying and working at home. Some households infer the benefits of concentration in their children's study when electric lights replace kerosene lamps, because children are also free from the odour and harmful pollutants emitted by kerosene lamps. As the interrelationship between electric lights and school records is not directly related, households seem to positively evaluate the benefits of electric lighting for children.

5.2. Enabling the watching of TV

Having SHS allows households to watch (black and white) TV, and household members can enjoy watching updated news and entertainment programs. As indicated in Table 8, the number of SHS households that obtained a TV increased, with more than 75% of SHS households now having a TV. In contrast, only 13.3% (41 of 308) of non-SHS households have a TV. No households, including both SHS-households and non-SHS households, have more than one TV or a colour TV.

As indicated in Fig. 5, the adoption of TV use generates several benefits for SHS households. More than 95% of households mention the benefits of access to entertainment programs, and 57% of households refer to updated news. The ratio of households who inferred the watching entertainment programs solely is higher in 40 Wp adoption case. As the generation capacity of SHS is limited, households that installed smaller packages may only be able to watch TV for a limited time. Moreover, 68% of households said neighbours frequently came to their home, indicating that the benefits of TV expanded to households without TV. Interestingly, even it is not the positive benefit; some households mentioned a negative impact for children in that they lacked concentration in their studies because of TV. We suggest that as TV is a relatively new piece of equipment for most households, it may still be a distraction for children.

5.3. Enabling the recharging of mobile phones at home

Mobile phones have rapidly diffused into rural households in Bangladesh. However, if they do not have rechargeable batteries at home, many people are forced to recharge their mobile phones either at the market or at a neighbour's or friend's house that has

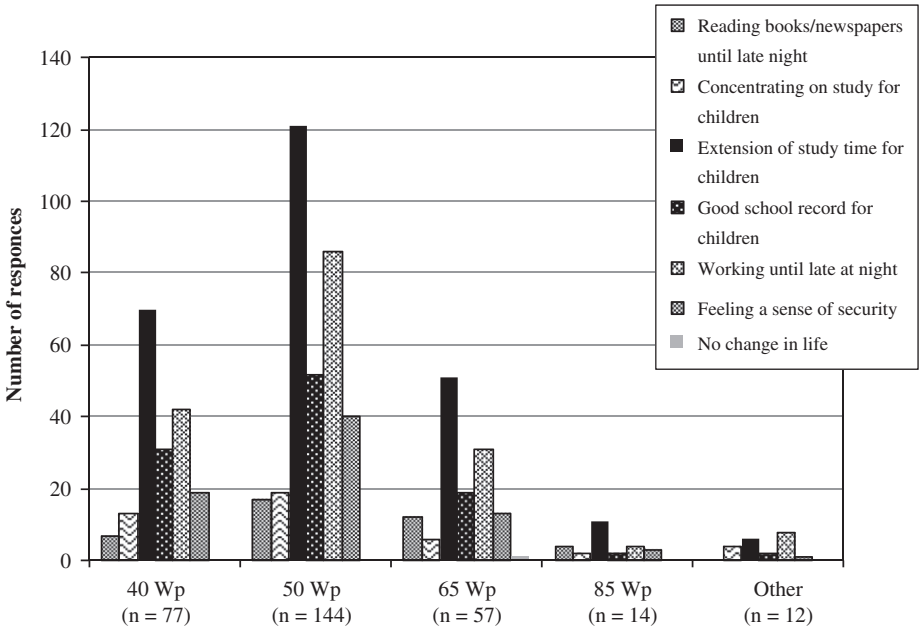

Fig. 4. Benefits of electric lighting for households (multiple responses).

Table 8
Change in TV use.

	Before	Now
40 Wp (n=77)	24	61
50 Wp (n=144)	58	111
65 Wp (n=57)	18	44
85 Wp (n=14)	3	9
Other (n=12)	1	7

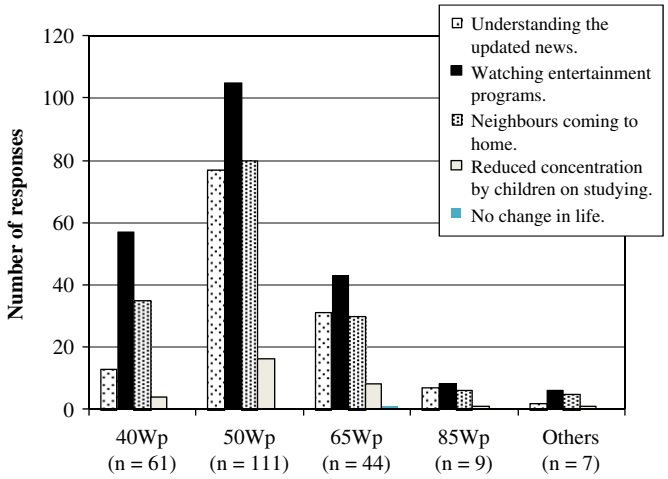

Fig. 5. Benefits of TV for households (multiple responses).

access to electricity. Having SHS allows households to recharge mobile phones at home, and therefore brings greater comfort for household members.

Table 9 provides the number of mobile phones in both SHS households and non-SHS households. Of the 304 SHS households, 220 households had at least one mobile phone before installing

Table 9
Number of mobile phones.

Number of mobile phones	Number of non-SHS households	Number of SHS households	
		Before	Now
0	128	84	9
1	157	172	166
2	16	37	91
3	6	7	21
4	1	4	10
5	0	0	7
Average number of mobile phones (per household)	0.69	0.93	1.60

SHS, and 295 households have a mobile phone now. The average number of mobile phones has increased from 0.93 to 1.60 units per household. Of these 220 households, 105 charged their mobile phones at the market and 49 at the house of a neighbour or friend before installing SHS.[4] On the other hand, 180 households among the 308 non-SHS households have mobile phones, and the average number of mobile phones per household is 0.69. Of these 180 non-SHS households, 93 recharge at the market and 74 at the house of a neighbour or friend.[5]

To evaluate the amount of work required for mobile recharging, Table 10 indicates the distances and the frequency of visit to the recharging place. If household members go to market areas to recharge their mobiles they need to walk for 20 min (one way), in addition to the charging time. While the neighbour's or friend's house is often located nearer to their home, they are still obliged to go outside for recharging. The more mobiles households have, the more frequently they will recharge their mobiles. The recharging

[4] Sixteen households recharged at both the market and a neighbour's or friend's house.

[5] Twenty-one non-SHS households recharged at both the market and a neighbour's or friend's house.

Table 10
Distance and the frequency of visits to a recharging place for mobile phones.

		Non-SHS households	SHS household (before)
To market	Distance (one way, km)	1.55	1.82
	Duration (one way, minutes)	17.14	20.49
To neighbour's or friend's house	Distance (one way, km)	0.10	0.32
	Duration (one way, minutes)	6.03	7.82
Frequency of charging (per week, per each mobile)		2.76	3.21

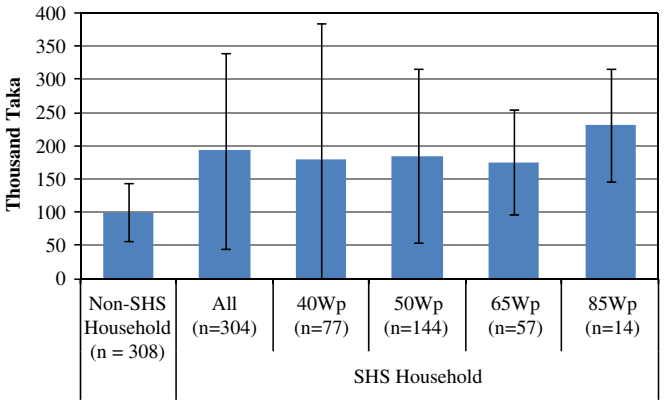

Fig. 6. Distribution of annual household income among SHS and non-SHS households. *Note*: The income of non-SHS households to their income in 2008. The bar indicates the half of standard deviation. Only the holders with major type of SHS are indicated. 1 USD is equivalent to 68.60 taka, as of 2007-08 (Bangladesh Bureau of Statistics, 2009). *Source*: Komatsu et al. (unpublished).

of mobile phones at markets is often free, or provided at low cost (5 taka), therefore the benefits of the opportunity for mobile recharging are characterised not so much by the monetary impact as by the decrease in the amount of work involved in recharging. As the number of households who charged at the marketplace in the category of SHS-households occupy the majority, the SHS creates additional opportunities for charging mobiles.

6. Future demands on SHS

Providing SHS at an affordable price is the key objective for expanding the benefits of SHS. Price reductions for SHS will encourage potential users, and the benefits available to SHS households will increase.

Of 308 non-SHS households, 268 knew about SHS. In addition, 188 households responded that the reason for not purchasing SHS was that they did not have sufficient funds for the installation. Against this background, there are significant differences in terms of household income among SHS households and non-SHS households. Fig. 6 shows the distribution of annual household income for SHS and non-SHS households. The income of SHS households refers to their income before installing the SHS (i.e., one year before SHS installation). In order to maintain comparability, all income indicators use 2008 prices adjusted by the annual average consumer price index (IMF, 2009). As indicated in Fig. 6, the average income level of the SHS households is twice as high as that of the non-SHS households, and there are statistically significant differences among SHS households and non-SHS households (two-sample, two-tailed *t*-test, significant at the 1% level). The figure also shows the breakdown of household income by the size of SHS installation. As shown, there are no statistically significant differences between SHS households, even at the 10% significance level (two sample, two-tailed *t*-test). These results indicate that the affordability of SHS is limited to the more affluent segments of the rural population. As the rural electrification ratio in Bangladesh is still only about 28% (IEA, 2009), there is a huge potential demand if SHS becomes more affordable.

For analysing the potential demand in accordance with price reductions for SHS, we provide the price-reduction scenario for non-SHS households. First, non-SHS households are shown the SHS packages (40, 50, 65 or 85 Wp) provided by the Grameen Shakti, whose components are the same as in Table 1, but with prices discounted by 10%.[6] The prices of each package are listed in Table 11. The current payment schemes apply: customers pay 15–25% of the total price of the package as a down payment, with the balance paid over a two- or three-year repayment period subject to a low interest rate (6–8%).They are requested to inform us whether they will purchase any package, do not purchase any, or have no decision. Afterwards, non-SHS households are asked what their decision is if the price of SHS was further discounted to 30%.

Fig. 7 indicates that around 61% of the non-SHS households show their desire to purchase SHS if the prices decrease by 10%. The majority of households selected the 40-Wp package. The potential demands are relatively higher in Manikganj and Kishoregonj than in Comilla. In Comilla, the electrification ratio is a bit higher than the other districts, so the prospects of grid electrification in Comilla may affect their decision. The price decrease of 30% encourages not

[6] The conventional means of finding the potential demand for commodities by customers are stated preference methods. Typically, choice experiments ask respondents to select from several alternatives. This study does not use a choice experiment because we cannot separate the attributes of each package into alternatives to ensure authenticity.

only the decision on purchasing SHS but also a demand shift to larger packages. Some 68% of non-SHS households showed their desire to purchase SHS if the price discount was 30%. Further, price reductions of 30% encourage more households to purchase 50-Wp or larger packages. This result confirms that a fall in price encourages the potential demand for non-electrified households and the further diffusion of SHS for rural electrification.

7. Conclusion

This research examines the benefits of adopting SHS and the future dissemination potential of SHS in rural Bangladesh. Given the rapid dissemination of SHS, this research attempts to assess whether the micro-benefits generated by SHS create tangible impacts for rural households, and examines the potential for accelerating the demand for SHS by reducing its price with a price-reduction scenario. By the use of case studies in Bangladesh, this paper attempts to highlight further diffusion scenarios when price reduction of SHS has been achieved.

Table 11
The list of offered prices for SHS.
Source: Current package referred by Grameen Shakti (2009b). The exchange rate is from the Bangladesh Bureau of Statistics (2009).

Capacity	Package price with 10% discount	Package price with 30% discount
40 Wp	20,250 taka (US$295)	15,750 taka (US$230)
50 Wp	25,200 taka (US$367)	19,600 taka (US$286)
65 Wp	30,600 taka (US$446)	23,800 taka (US$347)
85 Wp	38,250 taka (US$558)	29,750 taka (US$434)
	We will not purchase either package	We will not purchase either package
	We do not know	We do not know

Note: As only one SHS household selected the 130-Wp package, we have omitted 130 Wp from the list because it seems unrealistic to consider that non-SHS households would purchase this package.
US$1 was equivalent to 68.60 taka in 2007–2008.

This study found that most households could be free from kerosene and rechargeable batteries, and the reduced costs of those energy sources accounted for 20–30% of the monthly payments on SHS. We confirm that even though households have paid the monthly fee, they can still offset a certain amount. At the same time, the avoidance of kerosene consumption and a reduction in dependence on rechargeable batteries both contributed to reductions in fossil fuel consumption in Bangladesh. This implies that the adoption of SHS also helps reduce GHG emissions at the household level. In addition, this research highlights the lifestyle benefits in terms of the use of electric lights, watching TV, and the recharging of mobile phones. Electric lamps provide a better quality of lighting, which not only improves the indoor air quality but also creates a better environment for studying and working at home. Watching TV provides opportunities for enjoying entertainment programs and understanding updated news. SHS makes mobile phone recharging possible at home for those who previously went outside the home for recharging. Therefore, the benefits are obvious. These findings indicate that even though the scale of single SHS is small, the micro-benefits for households are significant.

The dissemination of the benefits of SHS could be further accelerated through price reductions in installation. For instance, a 10% price reduction encouraged 61% of non-SHS households to consider adopting SHS, and a 30% price reduction provided the incentive for 68% of non-SHS households to consider purchasing SHS packages. Further, a price reduction of 30% encouraged not only a decision on purchasing SHS but also a demand shift toward larger packages. The PV module usually accounts for the majority of system capital costs (Byrnes et al., 1998; Stutenbäumer et al., 1999), the price reduction on the SHS packages will be achieved by price reduction in solar panels, and will promote sustainable rural development with solar photovoltaic technologies in Bangladesh. This suggests that further research should attempt to analyse how to mix policy tools with the aim of maximising consumer interest and reducing the price of SHS for further dissemination of the micro-benefits for households.

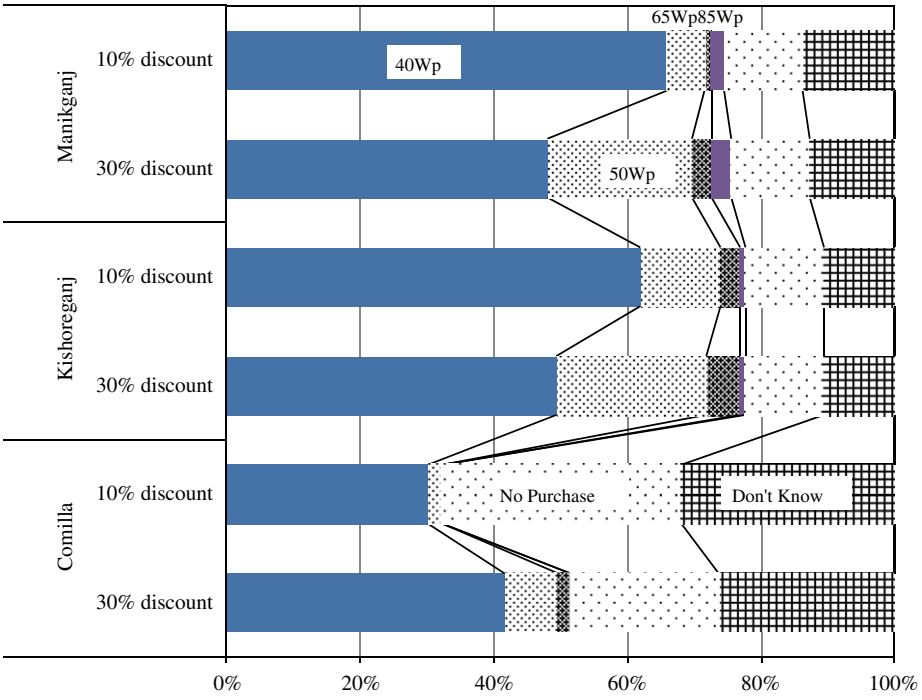

Fig. 7. Potential demand for SHS with the price difference scenario.

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