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The Benefits of Solar Home Systems

An Analysis from Bangladesh

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Abstract

The Government of Bangladesh, with help from the World Bank and other donors, has provided aid to a local agency called Infrastructure Development Company Limited and its partner organizations to devise a credit scheme for marketing solar home system units and making these an affordable alternative to grid electricity for poor people in remote areas. This paper uses household survey data to examine the financing scheme behind the dissemination of these solar home systems, in particular the role of the subsidy; the factors that determine the adoption of the systems in rural Bangladesh; and the welfare impacts of such adoption. The paper finds that while the subsidy has been declining over time, the demand for solar home systems has seen phenomenal growth, mostly because of technological developments that have made the systems increasingly more affordable. Households with better physical and educational endowments are more likely to adopt solar home systems than poor households. The price of the system matters in household decision making—a 10 percent decline in the price of the system increases the overall demand for a solar panel by 2 percent. As for the benefits, adoption of a solar home system improves children's evening study time, lowers kerosene consumption, and provides health benefits for household members, in particular for women. It is also found to increase women's decision-making ability in certain household affairs. Finally, it is found to increase household consumption expenditure, although at a small scale.

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The Benefits of Solar Home Systems: An Analysis from Bangladesh

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1. Introduction

Provision of electricity is a recognized development agenda item and one of the key pillars of the Sustainable Energy for All (SE4ALL) Initiative of the United Nations. According to a World Bank report, some 1.2 billion people do not have access to electricity, which limits their opportunities to improve their welfare. Most of these people are residents of 20 developing countries in Asia and Sub-Saharan Africa, and about 80 percent live in rural areas in those countries (World Bank 2013). Electricity is in fact an integral component of socio-economic development, with benefits ranging from enhanced income, productivity and employment due to access to electronic media and improved household lighting (Cabraal, Barnes, and Agarwal, 2005; Dinkelman, 2011; Khandker et al., 2012). Lacking access to electricity is therefore considered a major impediment to development.

But efforts to provide modern energy such as electricity for lighting, heating, cooking, and other production purposes face enormous challenges. Poor households in most countries typically have limited access as well as limited ability to pay for quality energy services. Better access to modern energy means being able to afford and use electricity. Despite national efforts with donor support, expansion of the national electricity grids in many poor countries such as Bangladesh is very slow, mostly because of limited electric generation and supply resulting from the lack of price and institutional reforms in the power sector (Barnes, 2007; Zerriffi, 2011).

With increasing technology development via alternative sources of electricity generation such as solar power, off-grid electrification becomes a viable alternative to the conventional approaches to electrification (Jacobson, 2007; Wamukonya, 2007; Zerriffi, 2011; Brass et al., 2012). A decentralized energy generation mechanism based on solar photovoltaics, for example, has gained currency in recent years for promoting solar power as part of achieving universal electrification in the developing world. However, the success of off-grid electrification models has also been limited as it depends critically on consumer demand. Lack of income is a serious bottleneck toward adopting solar home systems (SHS). Poor households must use their limited income to pay for electricity in addition to other essential livelihood items, and thus, the spread of SHS has proved challenging (Nieuwenhout et al., 2001; Friebe, von Flotow, and Täube, 2013).

How can the spread of these new technologies such as solar panels be promoted? What could promote SHS adoption, given limited household income and knowledge about solar panel technology? Although the importance of solar home systems has been recognized for decades (Nieuwenhout et al., 2001), there is not much research addressing how and when such technology can be promoted. There are a few studies found in the literature that explored the key determinants of early adoption of SHS when such technologies are made available (Lay, Ondraczek, and Stoever, 2012; Rebane and Barham, 2011; Komatsu et al., 2011). Household income matters a lot, as do other factors such as cost and technology. Because income is limited, any price support toward reducing the cost of SHS purchase and maintenance appears to be an option for accelerating SHS adoption in the poor countries.

Bangladesh's example of SHS expansion to more than 1.9 million households in rural areas has drawn the attention of both donors and governments of other countries. The phenomenal coverage of such expansion within a short period of time has been possible in part because of the subsidy provided by donors to facilitate SHS adoption in remote and off-grid areas. Provision of affordable SHS with maintenance services has become a national program of the government supported by the World Bank and other donors by establishing an autonomous and independent body known as the Infrastructure Development Company Limited (IDCOL). Despite national efforts for promoting electrification, Bangladesh's electrification rate has been only 55 percent for the nation as a whole and only 42.5 percent in rural areas. One possible solution, perhaps a stop-gap one, is thus to supply electricity through solar photovoltaic units under a specialized financing scheme introduced through IDCOL.

Bangladesh's SHS expansion program is run by IDCOL and its collaborating partner organizations (POs). But although 1.9 million SHS panels have been installed, this figure represents no more than 5 percent of the off-grid households. That means there is still enough scope for SHS expansion, particularly given that the supply of grid electricity at present faces enormous constraints including the limited supply and high cost of primary fuel, particularly oil, and lack of funds. How to provide electricity to people, even in a limited manner, while demand is increasing remains a challenge to policy makers. Much information is needed; in particular one must know the reach and effectiveness of the SHS technology, particularly in terms of serving the needs of the people by improving the quality of life as well as meeting electricity needs for productive purposes, wherever applicable. Additionally, it is necessary to know whether the observed impacts of SHS on household welfare recommend its expansion to reach more people in the off-grid areas.

The installation of an SHS on the rooftop of a house can have immediate impacts: it enables the household to have light after nightfall, makes study easier in the evenings, allows people to watch TVs and be informed of many useful and socially desirable things that are happening around them and perhaps be inspired to take part in such activities. Furthermore, it can lower indoor pollution levels as the household reduces its use of kerosene, and households may even earn some money by renting mobile phone charging services. Solar electricity also has possibly the positive externality of substituting for fossil fuels in generation of electricity and thus contributing to lowering of emission of carbon dioxide and harmful effects of climate change. The objectives of the present study are as follows: (a) Identify which rural households in off-grid areas adopt solar home systems and why; (b) Assess the direct and indirect effects of SHS adoption on the households and its members, in particular, children and women; and (c) Investigate the cost-effectiveness of the system for the adopters.

The paper is organized as follows. Section 2 presents a description of the SHS market and its size as well as the policies of IDCOL in promoting SHS adoption and expansion. Section 3 discusses the data and provides a descriptive analysis of various indicators relevant to the energy consumption from SHS units, appliances used, energy consumption patterns by SHS capacity, and the distribution of household wealth, which is a major factor influencing the adoption of SHS in rural areas. Section 4 presents an econometric framework for estimating the demand for SHS and its effect on household and intra-household welfare. Section 5 discuses the determinants of SHS adoption and identifies the role of price, income and non-price factors that have spurred the phenomenal growth in SHS expansion in rural Bangladesh. Section 6 reports the estimated effects of SHS adoption on household and intra-household outcomes using propensity score weighted regression given the cross-sectional nature of post-intervention impact evaluation. Section 7 examines whether SHS adoption is cost-effective and Section 8 concludes the paper.

2. The Bangladesh SHS Market: Growth, Price and Subsidy Policy

Solar Home Systems have been introduced as the solution to the demand for electricity in off-grid areas. However, this will probably be an interim solution given the existing technology and affordability, as an SHS unit cannot satisfy the whole range of a household's electricity demands. Still, SHS is a vastly superior alternative to using traditional fossil fuels to meet energy demand, not to mention that people on the grid may also want it as a back-up in case of power failures. Apart from the social considerations related to renewable energy and carbon emission issues, people demand more assured and cost-effective energy. The question therefore is whether SHS is the best available mechanism to provide 'light' to rural households who are not likely to get grid electricity in the near future. Also, it is important to examine whether the approach (of promoting SHS in remote villages) is cost-effective for households.

IDCOL has been pivotal in promoting SHS in Bangladesh through its partner organizations (POs), four of which account for most of the SHSs installed so far – Grameen Shakti, Srizony, RSS, and BRAC, with Grameen Shakti responsible for 58% of the units. POs are not only responsible for selling SHS units, but are also expected to develop a robust market chain for SHS systems so that it sustains beyond the period of intervention by IDCOL.

The IDCOL program has been supported by the World Bank, German Development Cooperation (GIZ), Kreditanstalt für Wiederaufbau (Reconstruction Credit Institute of Germany), EU, ADB, IDB and a multi-donor trust fund, GPOBA. The Rural Electrification Board (REB) also has its own SHS program but its numbers are comparatively few. Besides, unlike the IDCOL system, SHSs installed by REB are owned by REB itself, while the users only pay a fixed monthly fee for using the system.

The information up to February 2013 indicates that just one PO, Grameen Shakti, accounted for 56 percent of the SHS that have been installed (Figure 1). Three more POs viz. RSF, BRAC, and Srizony Bangladesh had installed respectively 15, 5 and 4 percent of the SHS.

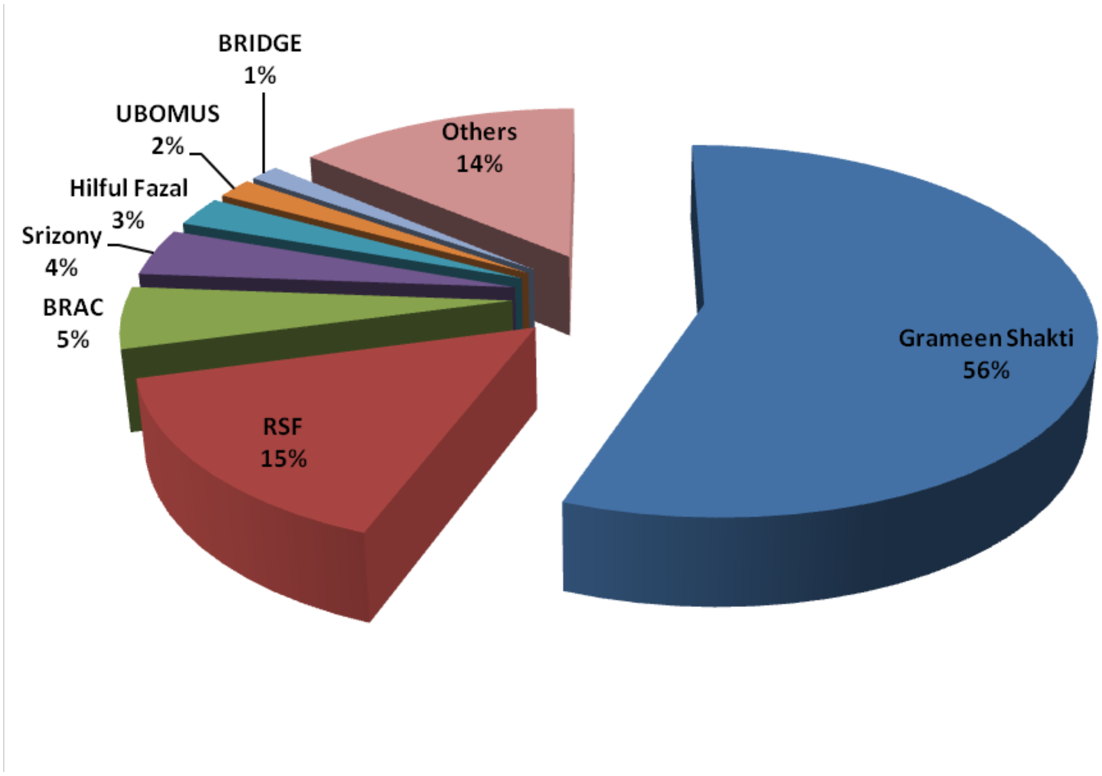


Figure 1: Distribution of cumulative installations of Solar Home System by POs

The financial viability of SHS is a major issue in its implementation. How the clients self-select into the program depends among other things on the price of the particular module that is on offer, credit availability and the cost of alternatives to electricity, especially kerosene which itself is also subsidized (Komatsu et al 2011).

Under IDCOL sponsorship for SHS financing, a down payment has to be made and also a payment in installments that carries interest. For example, a 50 Wp system may cost the household a total of nearly US$ 400, a hefty sum in rural Bangladesh (Haque et al., 2013).[1] It would be interesting to see which types of energy are being substituted for, and to what extent. If the changes are significant, one may try to analyze

[1] Wp (watt-peak) of a SHS unit represents the system capacity in terms of maximum wattage supported. That is, the combined wattage of the all the appliances that can be connected to the system simultaneously must not exceed the Wp of the system.

their (unintended) implications. It is necessary at least to find out if expenditures for energy services have changed for households with SHS, particularly for lighting services and storage electricity of various types that may be used for running a TV and other services. In extreme cases, various other expenditures may also change. Thus an attempt may be made to find out the general expenditure patterns for households with SHS and those without.

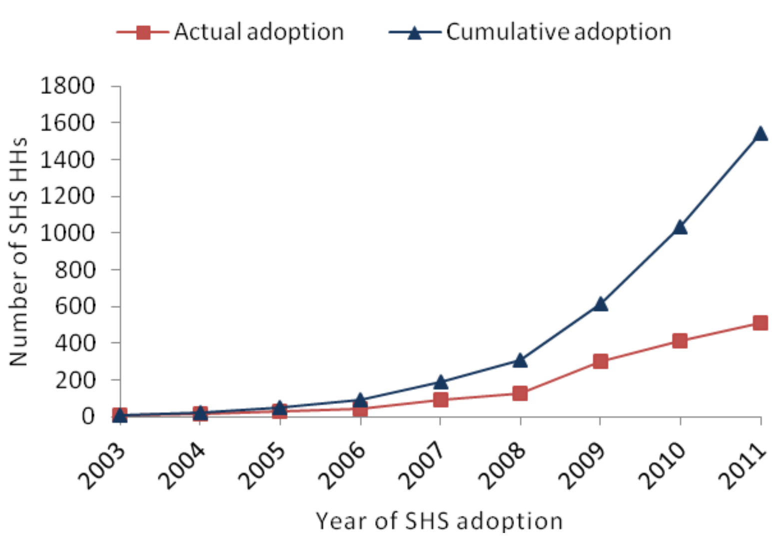
The impact on households would depend on what prices they actually pay, which depends on the behavior of the POs, given that there are several incentives that are on offer to them. The POs are provided several incentives. These are: (a) A buy-down grant (on average about 10 percent of the original cost of SHS) provided by the EU is designed to help POs reduce the cost of SHS at the household level and also to promote SHS in remote areas; (b) Refinancing of their initial capital from IDCOL (80 percent of the credit extended to customers by the POs) at a flat rate of interest of 6 percent for a period of 6-8 years; and (c) A grant from the EU for 'Institutional Development' which is about 18 percent of the POs' contribution to the credit facilities (i.e. 20 percent of the credit provided by POs to customers). Against such direct incentives to POs, households receive the solar home system on credit for 3 years at a flat rate of 12 percent, thus providing further incentives to POs to reap the benefits from both the interest spread and the repayment period. Of course, that depends on specific circumstances, particularly the competition from other POs. There is also a provision for buy back of batteries and battery replacement when their life is over.

The objectives for such grants are to encourage the POs to pass on the subsidy as much as possible to the clients so that rural households receive SHS at a cheaper price and that a robust and regulated market chain is established at the rural level that ensures (a) quality of products, (b) environmental safety, (c) availability of facilities for repair and maintenance and (d) supply of spares, bulbs, etc. at the local level.

The rate of interest charged to SHS buyers by POs varies between 6 percent and 12 percent and the duration of loan is 3 years in most cases. At the same time, POs have also established a system through which buyers can buy SHS at discounted prices if the loan repayment period is reduced and/or buyers purchase the system using cash on delivery and installation. There is, within an apparently regulated marketing system, thus scope for flexibilities, making effective prices vary by PO and also by the nature of demand from the client.

Growth of SHS units based on aggregate IDCOL data and household survey data

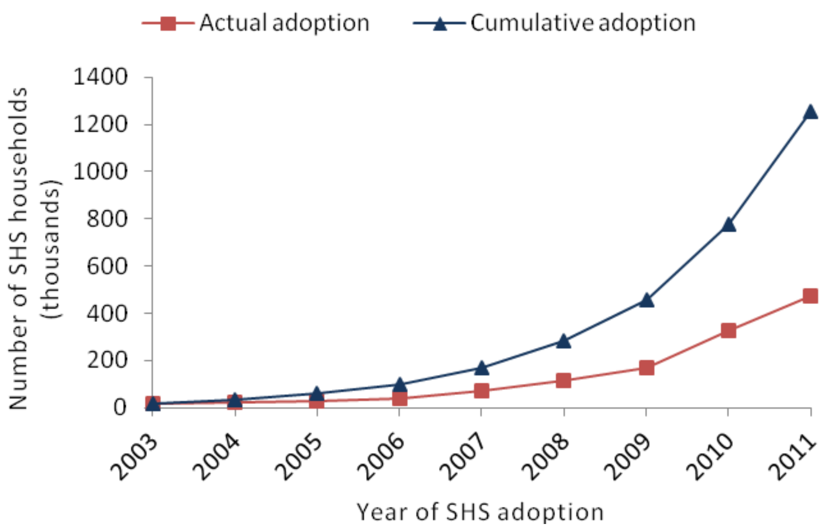
BIDS with the help of World Bank conducted a household survey in 2012 in both SHS adopted villages and control villages in order to study the role of IDCOL and its POs in the adoption of SHS and its effect on household and intra-household (more on the data in Section 3 below). The distribution of sample household data of 2,000 adopters of solar panels of different capacity over 2003-2012 is presented in Figure 2. The growth pattern of SHS adoption over the years shows that the household demand in the early years of marketing solar panels is much lower than that in later years, implying a market expansion only after a certain number of years of market experience with the solar panels.



Source: BIDS-World Bank survey, 2012

Figure 2: Yearly growth of SHS adoption from survey data

Interestingly, the national-level installation figures provided by IDCOL also mirror a distribution similar to what is observed from the household survey data (Figure 3). The expansion in the market actually took place after 2008 with exponential growth in the sale of SHS units. This shows that technology adoption always takes some years of experimentation and customer experience before it is accepted widely. For example, although IDCOL started to experiment marketing SHS around 2003, the total sales of SHS units was only 200,000 or so until 2008, after which it increased to 1.4 million in 2011. It is important to see what triggered this phenomenal growth in SHS adoption over a relatively short period of time.

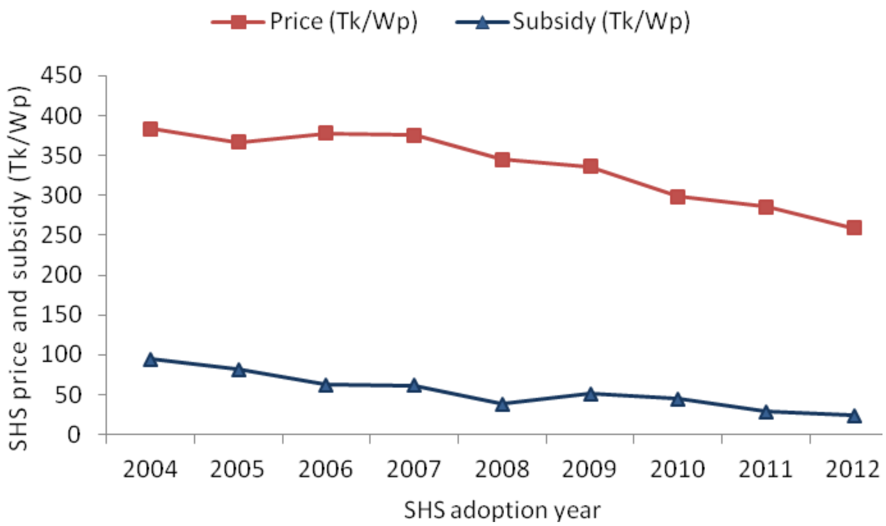


Source: IDCOL

Figure 3: Yearly installations of SHS in rural Bangladesh (national figures)

SHS price and subsidy over time

It is important to note that the solar panels marketed by IDCOL's POs were subsidized. Thus, grant and subsidized loan policies were introduced around 2003. Although the extent of the grant per unit solar panel has declined over time, the subsidy was nonetheless instrumental in pushing the frontier by shifting market demand through entry of small NGOs marketing various types of solar panels. With both PO competition and increased market demand, the price of SHS has declined despite the decline in subsidy. As Figure 4 suggests,

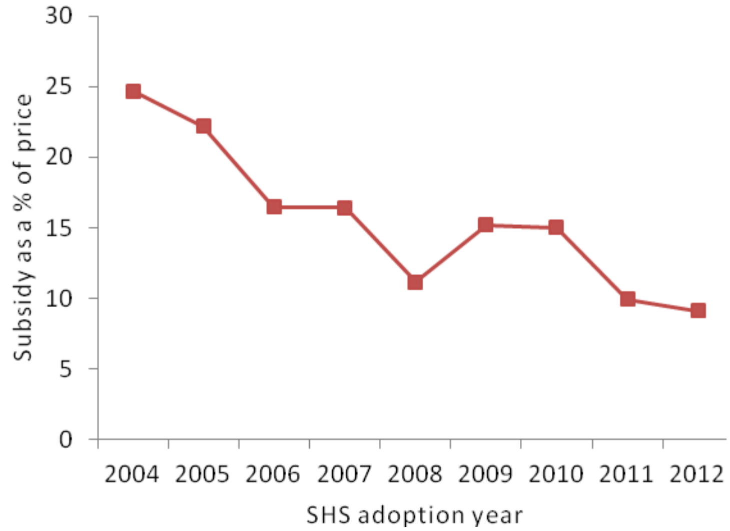


Source: BIDS-World Bank survey, 2012

Figure 4: Change in SHS price and subsidy over time

both the price offered to consumers and the subsidy offered to POs per unit of Wp have declined over time.[2] For example, in 2004, the offered price to the consumer per unit of Wp was close to Tk. 385 and the grant subsidy was Tk.95 per unit of Wp. By 2012, the unit price had dropped to Tk.256 and the grant subsidy to POs to Tk.25 per unit of Wp. This is an interesting scenario, as the prices of solar panels declined despite the decline in the grant subsidy given to POs. As Figure 4 suggests, the subsidy declined more rapidly than the price itself. In fact, as Figure 5 shows, the subsidy was about 25 percent of the SHS unit price in 2004 and dropped to less than 10 percent by 2012. Interestingly, despite the decline in subsidy and price support by IDCOL and its donors, the demand for SHS continued to increase. This was in part because of a steeper decline in the prices of solar units, thanks to technological advances in solar panels over time.

[2] The price per Wp is calculated by dividing the price of the system as offered to a rural customer by the capacity of the adopted system. The subsidy, on the other hand, has remained the same for all systems adopted in a single year and varied only by the year of adoption. So, subsidy per Wp is calculated by dividing the year-specific subsidy by the capacity of the system adopted by a customer. Finally, since rural households adopted SHS during different years the price and subsidy have been adjusted by the annual CPI (with base year 2000) to make these figures comparable across years.



Source: BIDS-World Bank survey, 2012

Figure 5: Change in subsidy as % of SHS price over time

3. SHS Adoption and Its Benefits: Descriptive Analysis

The study designed a large household survey among SHS adopters and non-adopters to examine the benefits and cost of SHS, as well as a survey of branch offices of the POs and a community survey to investigate the effectiveness of the technology and its delivery system on the cost-effectiveness of the systems to those who adopted them. A total of 4,000 households were surveyed in 128 villages evenly split between villages with an existing SHS supply (treatment) and those without SHS (control). (There were 1,600 SHS households and 400 non-SHS households in treatment villages, and 2,000 non-SHS households in control villages). The sample of treatment households was selected from a database of nationwide SHS customers maintained by IDCOL. (Table 1).

Table 2 shows the distribution of SHS adopters across seven divisions.[3] We see that the total number of treated households (2,000) sampled represent only 4.5 percent of the total population with Barisal division having the highest concentration of SHS users (13.4 percent), followed by Sylhet division (8 percent) and other divisions.

Energy consumption in SHS and non-SHS households

Households, regardless of their SHS adoption, are primarily dependent on kerosene and biomass for their energy requirements. About 80 percent of the households use fuel wood or non-fuel wood biomass for cooking and related activities (Table 3). While 62 percent of the SHS households use kerosene, the incidence is significantly higher, at 99 percent, among the non-SHS households. In contrast, uses of other sources of energy vary between 53 percent among the SHS households to 64 percent among the non-SHS households. Although a large share of households uses other sources, energy consumption from these sources is very low.

Insofar as the analysis based on the above percentage may be misleading, the actual energy consumption (in kgOE/month) was compared between SHS households and those without SHS. The results presented in Table 4 show that SHS households consume about 64 kgOE/month of energy from fuel wood vis-à-vis 51 kgOE/month for households without the SHS, and this difference is statistically significant. Similarly, SHS households consume 62 kgOE/month of energy from non-fuel wood biomass vis-à-vis 65 kgOE/month for households without the SHS. However, these empirical findings on biomass consumption are not important per se as the ownership of an SHS does not substitute these types of energy consumption. However, it may be noted that ownership of the SHS replaces consumption of fossil fuels such as kerosene among the SHS households. For example, SHS households consume less than 1 liter of kerosene per month, compared to almost 3 liters per month consumed by the non-adopters (Figure 3). This means that SHS adoption has probably reduced average household consumption of kerosene by 2 liters per month. The difference in the level of consumption of kerosene is statistically significant. But the overall consumption of

[3] The distribution figures in the sample are weighted to represent the national distribution of SHS users in rural Bangladesh.

energy does not differ significantly between SHS adopters and non-adopters, and hence, one can surmise that the use of SHS only changes the composition of energy consumption.

The substitution of kerosene

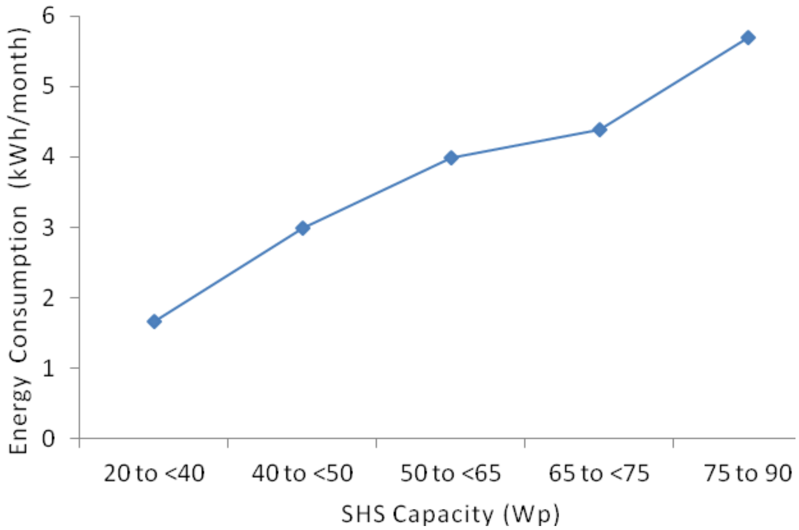
One of the main uses of the SHS is for lighting. Depending on the capacity of the SHS panels, households would have 2-5 lighting points. The more lighting points a household has, the lower the use of kerosene for lighting, which is mainly used in rural areas. While other possible uses of kerosene include cooking, this is a costly alternative to biomass cooking fuel and hence is rarely seen in rural households. Given that there are about 1.9 million SHS households in rural Bangladesh, the decrease in kerosene consumption amounts to over 40 million liters of kerosene saved annually due to SHS adoption.

SHS and appliance use

Even though the POs offer SHS of different Wp levels, most households choose 20, 40, 50, or 65 Wps. The most popular choice appears to be the 50 Wp size. As expected, there is a positive correlation between the size of the system and the number of lights that it supports; while only one lightbulb is used in a 20 Wp size, as many as 5 lightbulbs are used in an 75 to 90 Wp size unit of SHS (Table 5). Charger lights, one of the most common appliances, are used by 13 percent of all SHS adopters. Thirty-seven percent of the SHS households use SHS-powered electricity to run a television.

Energy consumption and SHS capacity

As Figure 6 suggests, energy consumption from the SHS panel increases with Wp size. This means consumption of energy form SHS must have alternative uses besides lighting. For example, with a higher-capacity SHS unit, households often purchase a TV, a source of entertainment and information for enhancing the productivity of inputs used in household production. Thus, the time use pattern of household members may change toward productivity-enhancing activities to boost their income. On the other hand, knowledge about health and education through TV programs can improve outcomes in these domains as well as give advantages to household members, especially women in SHS households, compared with those in non-SHS households. These changes are expected to contribute to improved welfare for all members of rural households in Bangladesh.

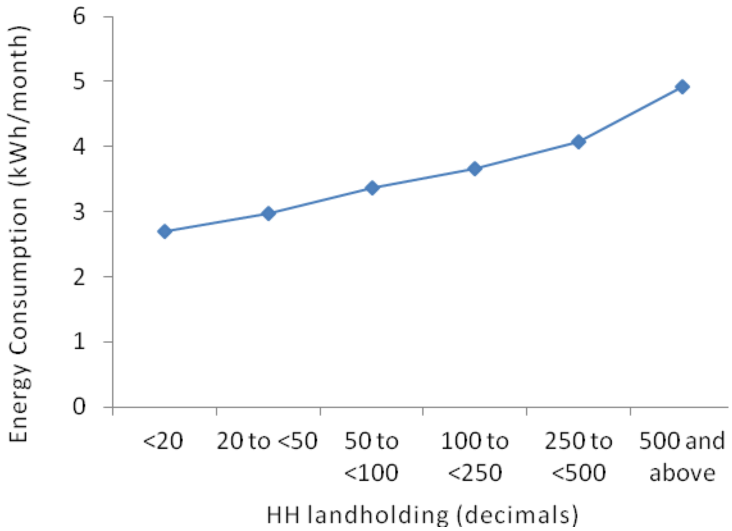


Source: BIDS-World Bank survey, 2012

Figure 6: HH energy consumption from SHS by SHS capacity

Energy consumption by wealth

The average price of SHS per Wp is approximately Tk.400 and the minimum size to purchase is 20 Wp, which costs Tk.8,000. This amount of money to be spent in purchasing this solar panel of minimum size is a lot of money for many rural households. Hence, those who can afford to purchase SHS panels are relatively wealthy households. In rural areas, landholding is a proxy for wealth. As Figure 7 suggests, energy consumption from SHS is higher with greater landholding, implying energy consumption is an increasing function of landholding. This implies that, as electricity/energy produced per unit of SHS is given, both household adoption of solar panels and panel capacity are positively related to landholding.



Source: BIDS-World Bank survey, 2012

Figure 7: HH energy consumption from SHS by landholding

4. Estimating SHS Demand and Its Effect on Welfare: An Econometric Framework

Several modules of the solar home system are on offer. A household or any other entity purchasing the solar home system from a PO may choose from models ranging from 10 Wp to 130 Wp. The most popular one is the 50 Wp model. While there is a wide range of uses of SHS, in a typical case, solar lights usually replace kerosene lamps or lanterns of various types. The most primitive of these lighting devices is a *kupi* (a one-wick lamp) used mostly in poorer households and also used by women in kitchens. Not only does the *kupi* emit heavy smoke inside the house as well as cause de-coloration of ceiling, walls, and other materials exposed to its surroundings, but it provides the dimmest of light. In general, the replacement of kerosene lamps reduces indoor air pollution and thus generates health benefits for households, in particular for women and children, who spend most of their time indoors. Therefore, the replacement of *kupi* compared to other kerosene lamps like lanterns may be especially advantageous for these households.

There are several packages of SHS on offer and the major difference among them is in terms of number of connection points. The more points there are, the more are the substitution scopes away from kerosene. On the other hand, the higher-output packages on offer are costlier and may be demanded mainly by comparatively well-off households. This hypothetically creates a differentiation in impact across households ranked by economic condition (wealth, assets, income, etc.). One needs to understand if this is the case; and if there are such differentials in impact, how pronounced they are. In any case, such differentiation also means that better-off households may be less exposed to indoor pollution and its consequences.

Very poor households may not have any designated covered spaces, as kitchen and cooking may be done in open space. Lighting from solar home systems is of little relevance in the context of indoor pollution in such cases. On the other hand, where there is a separate covered space such as a kitchen, in some cases it is located at a distance from the main rooms. As the normal solar home system operates well only within a given distance from the charge controller, which is usually located in one of the main rooms, kitchens that are located farther may go without any SHS lighting. Also, as the most popular modules usually offer only a few connection points, kitchens may again often go without lighting from solar electricity. In any case, this illustrates the importance of understanding both the number and the location of points of connection for lighting. The scope for kitchen lighting with solar electricity thus may be somewhat problematic.

The new lighting facility immediately extends waking and working hours in the evening and may have several types of benefits. Better lighting provides more time to do household chores and/or productive works probably at a somewhat unhurried pace. The better lighting facility may also provide more time for reading and study by students as well as non-students. Social interactions may increase, as may the sense of security due to lighting. Longer daylight hours may alter the time use pattern of both men and women, but possibly more for women. Some of these issues need to be investigated, keeping in mind the seasonal variations in daylight.

The provision of enough electricity for running a black and white TV may provide scope for entertainment as well as information which may be of value. Again, time use data will reveal if time for amusements has increased. One other potential benefit is that mobile phones, which are now ubiquitous even in villages, may now be charged at home. Prior to electrification, the owners of mobile phones would have to charge them at specific places and the frequency of commute perhaps would have been less had there been solar electricity in hitherto non-electrified houses. This also saves money for charging the mobile phones while providing an opportunity to earn an income by charging other people's mobiles.

The consumer surplus approach has been used to calculate and present the immediate effect of SHS adoption in terms of cost savings from forgoing alternative sources of energy such as kerosene that are replaced by an SHS panel. This method estimates the very short-run direct benefits of SHS. However, better light because of SHS provides other benefits, such as longer duration of study and income-generating activities during the evening hours. SHS power also provides other benefits by facilitating information flows for both consumption and production because of TV, which can be run with electricity generated by SHS. Thus, the benefits induced by SHS are much broader than the benefits induced simply by replacing kerosene for lighting. Therefore, the identification of wider benefits of SHS is a priority for policy makers to justify the subsidy used for promoting SHS. In other words, if the subsidy is large and the induced benefits of SHS in terms of cost savings of kerosene replaced are not enough to cover the subsidy, the project of subsidizing SHS will not be worth supporting. But if SHS adoption helps induce other measurable benefits such as better schooling, higher school enrollment (especially among girls), income generated during evening hours or improved health because of information flows via TV, a proposal for subsidizing SHS that has wider benefits will then be worth supporting.

The question arises: How do we measure the benefits induced by SHS adoption? To conceptualize the basic problem of identifying the benefits of SHS, consider the following household production function of household and individual-level outcomes such as education, health, income, expenditure, and time use represented by a vector (*H*) of a household *i* living in a village *j* using (*X*) amount of goods and services, conditioned upon the use of lighting services (*L*) and a set of exogenous village characteristics (*V*):

$$H_{ij} = \beta X_{ij} + \gamma L_{ij} + \delta^h V_{ij} + \mu_{ij}^h + \eta_j^h + \varepsilon_{ij}^h \quad (1)$$

where β, γ, and δ are parameters to be estimated, μ_{ij} are unobserved household-level characteristics, η_j unobserved village-level characteristics, and ε_{ij} independent error terms uncorrelated with any of the regressors. However, unlike *X* determined only by market-controlled prices, *L* is determined by the same factors that condition the household production of welfare goods (*H*) using the technology used to produce light that is combined with *X* to produce welfare goods (*H*) in the following manner,

$$L_{ij} = \alpha X_{ij} + \delta^l V_{ij} + \mu_{ij}^l + \eta_j^l + \varepsilon_{ij}^l \qquad (2)$$

Introducing modern technology (*S*) such as SHS to produce electricity to generate better and cleaner lighting for household production and consumption means a shift in the production technology of lighting. This means rewriting equation (2) as follows:

$$L_{ij} = \alpha X_{ij} + \delta^l V_{ij} + \pi_k S_{ijk} + \mu_{ij}^l + \eta_j^l + \varepsilon_{ij}^l \qquad (3)$$

$$\pi_k = \pi_0 + \pi(H_j;\tau) \qquad (4)$$

Equation (4) suggests that the price of an SHS unit is not given but depends on a number of factors, including an aggregate measure of community welfare ($H_j = \Sigma H_{ij}$) and the rate of subsidy (τ) provided by IDCOL to POs to entice household demand for SHS. If there are no factors that differentiate equation (3) from (2) and hence, (1), there is no way to estimate the separate effect of SHS adoption on the level of household welfare. For example, as equation (4) suggests, if the SHS price and its adoption depend only on aggregate community welfare (aggregate over household welfare), then equations (1)-(3) are indistinguishable and there is no way one can measure the effect of SHS on household welfare.[4]

The objective of the impact evaluation is to assess how adoption of the SHS affects household welfare. However, in the case of use of SHS, a possible simultaneity arises as causation may run in the reverse

[4] Similarly, if the basic price of SHS irrespective of subsidy is non-zero $(\pi \neq 0)$ it can also be a determinant of the independent effect of SHS on the welfare. However, the price of SHS unit is not truly exogenous as IDCOL through POs influences the price of SHS.

direction: from household outcome such as income to SHS connection. The household's decision to adopt the SHS may depend on income and a vector of additional determinants. Another problem occurs if some of the determinant variables are unobservable. Consider the households that are more motivated or risk-takers. They might be more inclined to purchase an SHS. At the same time, these generally unobservable characteristics may affect the outcome variable. Hence, differences in outcome would be assigned to the SHS adoption, even though they are in fact due to unobservable differences in characteristics. This is commonly referred to as omitted variables or selection bias in the econometrics literature.

Since no baseline data are available on the adoption of the SHS in Bangladesh, the difference-in-difference technique, a common method for impact evaluation, cannot be applied. There are three contending non-experimental methods available for ex-post impact evaluation in such a situation, namely regression discontinuity design (RDD), instrumental variables (IV) and propensity score matching (PSM) methods (for details, see Khandker, Koolwal and Samad, 2010). It may be noted that program placement, i.e. the choice of villages, is endogenous in that the treated villages must be off the grid in order for the POs to sell a particular system and receive refinancing and subsidy through the IDCOL. However, once a PO is established in a particular village, all of the households are eligible to purchase an SHS if they so wish.

Unlike interventions such as microcredit programs where targeting is based on land ownership or the gender of the household head, there is no definitive criterion for targeting households for the purpose of SHS adoption. This rules out the use of the RDD method which is applicable in case of explicitly specified exogenous rules such as the one used for microcredit targeting in the country.

The IV method involves finding creditable instruments that are highly correlated with program placement or SHS adoption but not with unobserved characteristics affecting outcomes. However, finding suitable instruments for SHS adoption is a formidable task.

Due to lack of credible instruments, we propose an alternative method known as the propensity score matching (PSM) method in the literature. The idea is to match program participants with non-participants using typical individual and community observable characteristics, despite the shortcoming of unobservable variable bias. In this case, each SHS participant is paired with a small group of non-participants in the comparison group that are most similar in the sense of probability of participation in the program. This probability (called propensity score) is estimated as a function of individual characteristics typically using a logit or probit model. The mean outcomes of these groups of matched non-participants form the constructed counterfactual outcome. The mean program impact is estimated by the difference between the observed mean outcome of the project participants and the mean outcome of the constructed counterfactual. Alternatively, we construct a p-score based on the probability function of SHS adoption, and use the p-score weighted regression to estimate the effect of SHS adoption.[5] The p-score weighted technique is better than the propensity matching method (PSM) as it does not involve sample attrition because of satisfying the balancing property (Hirano, Imbens, and Ridder 2003).

5. Determinants of SHS Adoption: Price Elasticity of SHS

Who purchases solar home systems to generate electricity for lighting and other needs? Given that the SHS price per unit has declined, we need to estimate the price elasticity of SHS panels. Very few studies have examined the determinants of SHS adoption. Wealthier households in a community are more likely to adopt SHS than their poorer counterparts when solar units are made available. Moreover, in some countries, households that are already on the electric grid are sometimes found to adopt solar home systems as well, suggesting that solar home systems are seen as a source of backup power for people who are willing to pay for electricity. Household adoption of SHS is also influenced by the education levels of household head or other members. However, it is not known how the price of SHS or prices of alternative fuels affect the adoption rate of SHS in areas where there is no grid electricity.

[5] In p-score weighted regression, the weight variable used in the regression is equal to 1/p for the SHS users and 1/(1-p) for the non-users, where p (propensity score) is the probability of adoption of SHS.

Assume that for a given amount of lighting or electricity services $(\hat{L})$ demanded by each household, equation (3) is expressed as follows where S_{ij} is a function of all exogenous factors including the given demand for lighting services of households:

$$S_{ij} = \rho_0 \hat{L} + \rho_1 X_{ij} + \rho_2 V_{ij} + \rho_3 \pi_0 + \rho_4 \tau + \mu_{ij} + \eta_j + \varepsilon_{ij} \qquad (5)$$

where, $\hat{L} = L(X_{ij}, V_{ij}, \pi_0, \tau)$ is also determined by the same exogenous factors that affect the living conditions including demand for lighting services. In other word, as equation (5) states, whether a household adopts/purchases an SHS unit would depend on household- and individual-level exogenous factors such as age and education of household head, land and non-land assets and village-level exogenous factors such as village access to roads and electricity plus a set of exogenous prices of alternative fuels including prices of SHS panels and subsidy rates for marketing the panels.

Table 6 presents comparative statistics of explanatory variables for the SHS adoption model of equation (5). The descriptive statistics are shown by SHS adopters, non-SHS adopters and all types of households to differentiate if the SHS adopters are different from their counterpart non-adopters in terms of major characteristics. We find that SHS adopters are headed more often by females, are more educated, and are much wealthier (in terms of both land and non-land assets) than non-adopters. The SHS adopters are also more likely to live in villages characterized by *char* land and subject to river erosion.[6] Adopters also tend to live in villages with higher incidence of primary and secondary schools, and higher presence of NGOs. On the other hand, SHS adopters live in villages that have lower presence of Grameen Bank and less connection to a paved road. This means villages that have paved roads and Grameen Bank are more likely to use alternative sources of electricity.[7]

As the adoption is a binary variable (1 if adopted, and 0 otherwise) we estimate equation (5) using a probit technique, assuming the error term follows a normal distribution. However, the literature on

[6] A *char* is a riverine island that forms as a result of river erosion and accretion. While *char* lands are highly vulnerable to flooding and erosion, millions of poor people in Bangladesh live there.
[7] Note that no village in our sample has grid electricity.

technology adoption suggests a logistic distribution (an S-shaped adoption curve implying very few adopt a new technology initially, but after a while when the technology is known, its demand increases exponentially). An alternative model is thus followed using a logit regression method. The results of both regression methods are presented in Table 7. But as we have seen earlier, SHS units are not homogeneous, as adopters can choose various levels of capacity. To see what variables determine the choice of various categories of SHS capacity units, we estimate a multinomial logit model for household adoption of different capacities of SHS and present the results in Table 8.

As Tables 7 and 8 suggest, female-headed households are more likely to adopt SHS panels than male-headed households and also to adopt SHS units with higher capacity. Younger heads of households are more likely to adopt an SHS panel with lower capacity. Higher education of either adult males or females means both a higher probability of adoption and the adoption of a larger-capacity SHS. Similarly, land and non-land assets increase the SHS adoption of higher capacity and the probability of adoption of low-capacity units is high for small landholding groups. This suggests smaller-capacity units are favored more by small-size farm households.

The price of alternative fuels such as kerosene, fuel wood and dung seems to affect the adoption of SHS when it comes to size of the unit, but not the adoption of the system in general (as shown in Table 7). In particular, the price of kerosene, which could be a substitute for SHS for the purpose of lighting, has a negative effect on the adoption of a low-capacity system. This implies that households decide to adopt higher capacity units if the price of the substitute fuel goes up. That is not surprising as higher capacity units are cheaper based on price per Wp and provide a better value. Of course, some fuels are better substitutes than others. The own price effect of SHS units is negative, meaning the lower the price of a solar panel, the higher the demand for a unit and hence a higher adoption rate of solar panels. The coefficients of own price are less than one, implying that the demand for SHS is price-inelastic. Thus, a 10 percent decline in SHS price increases the overall demand for a solar panel by 2 percent (as per the logit model).

The socioeconomic and agroclimate endowments of villages play also an important role in SHS adoption. The demand for SHS is higher in villages with higher incidence of primary schools, char land, and river erosion. These factors matter more for higher-capacity units than lower-capacity units of SHS. The presence of a BRAC program increases the adoption rate and for higher-size units. This is however not the case with Grameen Bank and other NGOs.

In short, both household and community characteristics influence the adoption rates of SHS. The prices of SHS units as well as other fuels are also found to matter. Income or wealth matters very much. Wealthier households demand higher-capacity units of SHS; the converse is true for poor households. Interestingly, the demand for SHS units is price-inelastic, implying that the price reduction through price support policies such as grants may not be the only option to spur growth in SHS adoption.

6. Welfare Effects of SHS: An Application of the Propensity Score Method (PSM)

As indicated earlier, we propose one variant of the propensity score method (PSM) to estimate the welfare effects of SHS adoption. As suggested by Hirano, Imbens and Ridder (2003), we first obtain the propensity score by estimating the adoption equation (logit or probit regression) and then calculate the weight variable. The weight variable gets a value 1 for the participants and p/(1-p) for the non-participants, where p is the propensity score (probability of SHS adoption). In the next step, we estimate a weighted outcome equation using the weight variable.

The welfare effects of SHS units may also vary not only by whether the households adopt but also how long they use solar panels and how much electricity they consume (in essence this means what capacity of solar units adopted). Therefore, two more models besides the adoption model are utilized to estimate the effects of solar power. The results are presented in Table 10.

There are a variety of outcomes considered in the paper. Table 9 presents the descriptive statistics of several outcomes. The outcomes are consumption of kerosene, hours spent on fuel collection, hours spent for study in the evening, incidence of morbidity among household members, women's decision-making power, and household per capita expenditure. The descriptive statistics are given by SHS adopters, non-adopters, and for all types of households. We find that there are statistical differences in several outcomes between adopters and non-adopters of SHS. Thus, solar power owners have higher food, non-food, and total expenditure than non-adopters. Kerosene consumption is significantly much lower (by more than 2 liters per month) than it is among non-adopters of SHS. Both boys and girls spend significantly more time for study during evenings in SHS-owned households than in non-adopter households. Although there are no statistical differences in the incidence of disease of various types, women's fuel collection time is much lower for SHS adopters than non-adopters. Also, women's decision-making ability in household affairs is higher for SHS adopters than non-adopters.

The key research question is, whether SHS adopters are better off (in terms of higher expenditure, for example) than non-adopters as a result of solar power or they were better off to begin with, as wealth (land and non-land assets) is a major factor influencing the decision to adopt a solar panel. It is also possible that when solar panels are available, more able households tend to adopt SHS so that the effect of SHS on behavioral outcomes such as study hours and per capita consumption are not so much due to SHS adoption itself but the unobserved ability effect of households.

The challenge is to determine whether SHS adoption has actually impacted household behavioral responses. As discussed in the methodological section, we would like to address this fundamental challenge by using the PSM technique. Let us consider the estimates of p-score weighed regressions for various outcomes of particular interest in Table 10.

As we know, the immediate effect of solar power is to replace kerosene. As Table 10 shows, kerosene consumption is reduced by as much as 68 percent because of SHS adoption. Our results also show that the adoption for an additional year reduces kerosene consumption by 33 percent. Consumption of solar power by 1 kWh per month reduces consumption of kerosene by 69 percent. These are substantial gains of SHS adoption. Households in rural areas also use fuel wood for lighting or cooking. Hence, one immediate effect is expected on the time use of women or children for fuel collection. We find in Table 10 that SHS adoption reduces women's hours of fuel collection by 9 percent. In contrast, one additional year of solar power exposure reduces women's time use by 4 percent. However, consumption of solar energy does not seem to affect women's pattern of time use.

The immediate outcomes of solar power are study hours of children as well as the morbidity of household members and changes in the decision-making power of women induced by TV use facilitated by solar electricity. We find that evening study hours of both boys and girls have increased as a result of SHS expansion. For example, boys study 8 additional minutes and girls study 7 additional minutes during evening when the household is connected to a solar panel. Solar power is found to reduce the morbidity of household members, especially female members. For example, SHS adoption reduces respiratory disease of women by aged 16 and above by 1.2 percent. This is perhaps possible if solar power is used for cooking that not only reduced the use of fuel wood for cooking, which may lead to decreased incidence of respiratory illness due to less air pollution. Women are also found to exercise some decision-making power, but that is only when a certain amount of solar power is consumed that facilitates running a TV. No wonder it is the consumption of electricity but not simple SHS adoption that matters more to this decision-making power.

The ultimate effect of electricity provided by SHS is on household consumption and income. There are a number of ways electricity through SHS adoption can facilitate growth in income and consumption. First, replacement of kerosene saves money that can be used for consumption of food and non-food items. Second, changes in time use and decision-making power induced by SHS adoption can help reallocate household resources for consumption and production, which increases both income and consumption. Third, solar power might help promote home-based income earning activities that have a direct effect on income, and hence, an indirect effect on consumption. Our results presented in Table 10 suggest that solar power increases per capita food expenditure by 9.3 percent, per capita nonfood expenditure by 4.7 percent and total per capita expenditure by 5.1 percent, either simply because of adoption of the SHS unit, or through longer exposure to solar power or higher amount of electricity consumption from solar units.

How do the welfare effects of SHS adoption compare to similar benefits due to grid electrification? A study using household survey data of 2005 from rural Bangladesh shows that grid connectivity improves household per capita expenditure by 11.3 percent (Khandker, Barnes, and Samad 2012). The same study also finds that the evening study time of boys and girls goes up respectively by about 22 minutes and 13 minutes. That is, the impacts of SHS adoption are similar in nature while being smaller in magnitude. Because of the limited utility and services possible by SHS, its benefits will never match those due to grid connectivity. However, such a comparison at least shows that the benefits achieved are in the right direction.

7. Cost Effectiveness of SHS

How much do the consumers of SHS pay against the lighting and other services provided by an SHS unit? How much do they benefit from an SHS system? Can accrued benefits by households outweigh the cost of the system charged to the households? There are various ways we can calculate the cost-effectiveness of SHS for households who adopted such a technology for generating electricity for a variety of uses.

First, let us quantify the extent of benefits generated from a solar system for an average household. Consider the case of expenditure savings because of reduction of kerosene consumption as a result of solar power generation. If an average household saves 2 liters of kerosene per month by adopting SHS, it means a savings of Tk. 160 per month (given that kerosene price is Tk. 80 per liter). This is the benefit (in terms of cost savings for lighting) of SHS. Next, consider the income/expenditure gains induced by SHS adoption. Estimates in Table 10 show that households accrue a 5 percent increase of total expenditure per month due to SHS adoption. This is equivalent to over Tk. 700 gains per month from solar power. This expenditure gain takes into account the savings in switching from kerosene to SHS.[8]

Now, let us consider the cost of SHS adoption. As per our data, the average unit price of SHS is Tk. 26,920 including the subsidy (2012 figures). If we spread this cost of the unit over its lifetime of 10 years, we get a monthly cost of a SHS unit of Tk. 224. When we divide the benefits (in terms of expenditure gain) by the cost of SHS adoption, we get a benefit-cost ratio as 3.1. That is, accrued benefits of a solar unit exceed its cost by 210 percent.

8. Conclusions

[8] This gain should not be interpreted as the increase in expenditure following the SHS adoption due to loan payments. It reflects, instead, a betterment of the quality of life accumulated through years of use of SHS. SHS had already been in rural Bangladesh for 10 years by the time our data were collected, with an average duration of 2.5 years for the sample. As such, such an accumulation of benefits is not surprising reflected through enhanced productivity, income and expenditure (a measure of welfare). .

Electricity is considered a powerful instrument for raising productivity and improving living conditions. However, universal electrification has not been attained. More than 1.2 billion people do not have access to electricity, many of whom live in South Asia and Sub-Saharan Africa. In Bangladesh, for example, less than 45 percent of rural households have access to electricity and the overall country-level access rate is not more than 56 percent. The barriers toward universal electrification are not only lack of income, but also the country's ability to generate and distribute grid electricity enough to meet demand. In this context, solar power using photovoltaic technology appears a promising instrument for promoting electrification in remote rural areas that would not be connected to the grid in the foreseeable future or for possible use as a feed-in to the grid in the future. Apart from the technological challenges of marketing solar home systems in remote areas, financing a solar power program is challenging for a number of reasons. Given the cost of the unit and its distribution problems, many poor households would find it difficult to purchase a solar unit out of their own pockets.

Because of lack of income and access to a financing facility to help purchase a solar panel on loans, the government of Bangladesh, with help from the World Bank and other donors, has aided a local company called IDCOL and its partner organizations (POs) to devise a financing scheme for marketing SHS. The objective is to make solar units available at a low price with easy access to a financing system under reasonable interest rates and acceptable loan duration. Apart from a financing scheme, the donors also provided a grant (although on a declining basis over time) in support of marketing solar units to POs of IDCOL. As the system of marketing SHS is subsidized, it is important to estimate the cost-effectiveness of acquiring a solar unit to generate electricity for millions who would likely never otherwise have access to electric power.

Our analysis shows that the subsidy was about 25 percent of the average price of SHS in 2004, but declined to 10 percent of the price in 2012. Analysis also shows that the demand for SHS is price-inelastic. This means POs can charge a higher price for a system at its cost (i.e., without any subsidy) perhaps without substantial reduction of market demand for SHS. However, given that the client base among the poor and the prices of SHS are proportional to capacities, it is understandable that wealth plays a critical role in promoting SHS adoption. That means the poor households who may prefer lower-capacity solar panel units (less than 40 Wp) may not even be able to pay the market price (without subsidy) of such a unit. That is, even if the subsidy is less than 10 percent of the current price, it seems IDCOL's subsidized operation of marketing SHS may not be discontinued for some time.

Thus, for adopters in rural areas, it is important to find out the socioeconomic benefits of SHS. The objective is to estimate benefits to compare and contrast with the costs of acquiring a solar unit. Using a large household survey data from Bangladesh, this paper estimates the effects of SHS on a variety of household and intra-household behavioral outcomes. We find that SHS adoption increases evening study hours of both boys and girls; reduces fuel collection time of women; helps adopt b/w TVs which in turn helps promote women's decision-making power and information sharing; and also reduces women's and children's morbidity from respiratory diseases by reducing kerosene consumption. SHS adoption also promotes household welfare by increasing per capita expenditure. Given the high cost of acquiring a unit plus the grant subsidy attached to each unit, we find nonetheless that the benefits accrued to households outweigh the cost of buying a solar unit. This means SHS is cost-effective for a rural household. Whether the social benefits generated through higher access to electricity via solar power also exceed the social cost (in terms of providing grant and subsidy support) of marketing such units is something worth exploring. Indeed, this issue is addressed in another paper that shows that the social benefits exceed social cost (Haque et al., 2013).

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Tables

Table 1: Sample distribution of the data

Sampling units	Numbers
Division	7
Districts	16
Upazilas	
Treatment	16
Control	16
Total	32
Villages	
Treatment	64
Control	64
Total	128
Households	
Treatment HHs	1,600
Control HHs in treatment villages	400
Control HHs in control villages	2,000
Total	4,000
Individuals	
From treatment HHs	9,555
From control HHs in treatment villages	2,243
From control HHs in control villages	10,869
Total	39,684

Source: BIDS-World Bank survey, 2012

Table 2. Extent of Solar Home System (SHS) adoption in rural Bangladesh (%)

Divisional Region	In villages with SHS	In all villages
Dhaka	20.5	4.1
Chittagong	24.8	5.2
Khulna	20.5	4.1
Rajshahi	11.3	2.1
Rangpur	13.3	2.5
Barisal	48.2	13.4
Sylhet	34.4	8.0
All regions	22.5	4.6
N	2,000	2,000

Note: Figures in this table and subsequent tables are weighted by actual distribution of SHS households at the region level, and so are nationally representative for rural Bangladesh.
Source: BIDS-World Bank survey, 2012.

Table 3. HH access to various energy sources by SHS use (%)

Energy source	SHS HHs (N=1,600)	Non-SHS HHs		
		From SHS villages (N=400)	From non-SHS villages (N=2,000)	From all villages (N=2,400)
Fuel wood	86.5	82.2	79.8	80.2
Non-fuel wood biomass†	78.1	80.0	84.4	83.7
Kerosene	61.6	97.0	99.1	98.7
SHS	100.0	0	0	0
Other sources‡	52.5	65.0	63. 8	64.0

†Non-fuel wood biomass sources are dung, tree leaves, crop residue, coal, jute stick, and briquette.
‡Other sources include LPG, candle, dry cell batteries, storage batteries, generators. Although a good share of households uses these sources, energy consumption from these sources are very low as we will see in the next table.
Source: BIDS-World Bank survey, 2012.

Table 4. Energy consumption from various sources by rural households (kgOE/month)

Energy source	SHS HHs (N=1,600)	Non-SHS HHs			t-statistics of the difference between SHS users and nonusers
		HHs from SHS villages (N=400)	HHs from non-SHS villages (N=2,000)	All non-SHS HHs (N=2,400)	
Fuel wood	63.57	55.68	49.61	50.64	4.48**
Non-fuel wood biomass†	61.87	61.20	65.48	64.80	-1.27
Kerosene	0.76 (0.92)	2.39 (2.91)	2.33 (2.82)	2.34 (2.84)	-23.62**
SHS	0.30 (3.56)	0	0	0	
Other sources‡	0.29	0.02	0.02	0.02	5.36**
All sources	104.32	97.05	97.21	97.18	1.30

†Non-fuel wood biomass sources are dung, tree leaves, crop residue, coal, jute stick, and briquette.

‡Other sources include LPG, candle, dry cell batteries, storage batteries, generators. Although a good share of households uses these sources, energy consumption from these sources is very low.

**Figures are statistically significant at a level of 5% or less.

Note: Figures are average values for households that actually use particular energy sources, that is, households with zero consumption are excluded from the calculation. The figure in parentheses is energy consumption in kWh/month for SHS and liter/month for kerosene.

Source: World Bank-BIDS survey, 2012.

Table 5. Appliance use pattern by SHS HHs by selected SHS capacities (%)

(N=1,505)

SHS capacity (Wp)	Share among SHS users (%)	Tube/CFL lights (number)	Charger lights/lantern	TV
20 to <40 (mostly 20)	17.3	1.0	9.0	5.8
40 to <50 (mostly 40)	23.9	2.4	8.7	33.2
50 to <65 (mostly 50)	36.1	3.3	13.2	46.1
65 to <75 (mostly 65)	12.9	3.8	23.4	50.7
75 to 90 (mostly 75 and 85)	9.8	4.7	18.6	49.6
All capacities	100.0	2.9	13.3	37.0

Source: BIDS-World Bank survey, 2012

Table 6. Descriptive statistics of key explanatory variables (N=4,000)

Explanatory variables	SHS households	Non-SHS households	All households
Sex of HH head (1=Male, 0=Female)	0.910	0.945	0.943
	(0.286)	(0.229)	(0.232)
Age of HH head (years)	45.6	45.2	46.1
	(13.2)	(12.9)	(12.9)
Max. education of HH adult males (years)	6.5	4.5	4.6
	(4.7)	(4.4)	(4.4)
Max. education of HH adult females (years)	5.7	4.1	4.1
	(4.0)	(3.8)	(3.8)
HH land asset (decimals)	242.6	114.3	120.2
	(524.4)	(187.9)	(217.0)
HH non-land asset ('000 Tk.)	4,515.1	1,700.9	1,830.6
	(15,295.8)	(5,935.8)	(6,887.8)
Village price of fuel wood (Tk./kg)	4.39	4.20	4.21
	(1.68)	(1.39)	(1.41)
Village price of dung (Tk./kg)	3.04	2.94	2.95
	(0.62)	(0.67)	(0.66)
Village price of kerosene (Tk./liter)	64.59	64.92	64.91
	(1.39)	(1.83)	(1.81)
Price of solar home system (Tk./Wp)†	318.12	316.92	316.97
	(40.53)	(13.05)	(15.44)
Village has primary schools (1=Yes, 0=No)	0.918	0.677	0.689
	(0.274)	(0.468)	(0.463)
Village has secondary schools (1=Yes, 0=No)	0.411	0.248	0.255
	(0.492)	(0.432)	(0.436)
Village is in *char* area (1=Yes, 0=No)	0.297	0.250	0.793
	(0.457)	(0.433)	(0.405)
Village is in a land subject to river erosion (1=Yes, 0=No)	0.248	0.180	0.814
	(0.432)	(0.384)	(0.389)
Village has paved roads (1=Yes, 0=No)	0.475	0.550	0.546
	(0.499)	(0.498)	(0.498)
Village has Grameen Bank (1=Yes, 0=No)	0.544	0.710	0.702
	(0.498)	(0.454)	(0.457)
Village has BRAC (1=Yes, 0=No)	0.892	0.782	0.787
	(0.310)	(0.413)	(0.410)
Village has other NGOs (1=Yes, 0=No)	0.766	247.1	247.5
	(0.423)	(55.5)	(55.5)

†Price of solar home system is calculated by dividing the price of the unit by the capacity of the unit. This price is the price of net of subsidy, if any.
Note: Figures in parentheses are standard deviations.
Source: BIDS-World Bank survey, 2012.

Table 7. Determinants of HH adoption of solar home system

(N=4,000)

Explanatory variables	**Probit estimates**	**Logit estimates**
Sex of HH head (1=Male, 0=Female)	-0.023**	-0.023**
	(-2.81)	(-2.74)
Age of HH head (years)	-0.0006**	-0.0006**
	(-3.22)	(-2.87)
Max. education of HH adult males (years)	0.002**	0.002**
	(4.06)	(3.65)
Max. education of HH adult females (years)	0.002**	0.002**
	(3.37)	(3.18)
Log HH land asset (decimals)	0.006**	0.006**
	(2.71)	(2.62)
Log HH non-land asset ('000 Tk.)	0.011**	0.011**
	(5.08)	(4.78)
Village price of fuel wood (Tk./kg)	0.0004	0.0004
	(0.09)	(0.08)
Village price of dung (Tk./kg)	0.005	0.005
	(0.46)	(0.46)
Village price of kerosene (Tk./liter)	-0.006	-0.005
	(-1.58)	(-1.55)
Log price of solar home system (Tk./Wp)†	-0.130**	-0.203**
	(-2.49)	(-2.37)
Village has primary schools (1=Yes, 0=No)	0.047**	0.053**
	(2.28)	(2.22)
Village has secondary schools (1=Yes, 0=No)	0.009	0.011
	(0.71)	(0.92)
Village is in *char* land (1=Yes, 0=No)	0.052**	0.051**
	(3.04)	(3.01)
Village is in a land subject to river erosion (1=Yes, 0=No)	0.047**	0.046**
	(2.42)	(2.32)
Village has paved roads (1=Yes, 0=No)	-0.010	-0.013
	(-0.65)	(-0.81)
Village has Grameen Bank (1=Yes, 0=No)	-0.015	-0.011
	(-1.01)	(-0.76)
Village has BRAC (1=Yes, 0=No)	0.038**	0.036*
	(2.06)	(1.80)
Village has NGOs (1=Yes, 0=No)	0.021	0.020
	(1.02)	(0.88)
Pseudo R^2	0.206	0.208

Note: Marginal effects are reported. Figures in parentheses are t-statistics based on robust standard errors clustered at village level. * and ** refer to statistical significance level of 10% and 5% (or less). Regression includes additional control variables such as availability of various development programs in village and fixed-effects of divisional regions.
Source: BIDS-World Bank survey, 2012.

Table 8. Determinants of HH adoption of SHS by capacity (multinomial logit estimates) (N=4,000)

Explanatory variables	SHS capacity				
	20 to <40	40 to <50	50 to <65	65 to <75	75 to 90
Sex of HH head (1=Male, 0=Female)	0.00005	-0.005*	-0.008**	-0.005**	-0.005**
	(0.02)	(-1.75)	(-2.08)	(-2.48)	(-3.45)
Age of HH head (years)	-0.0002**	-0.0001**	-0.0002**	-0.00003	-0.00003
	(-3.39)	(-2.18)	(-2.07)	(-0.52)	(-0.66)
Max. education of HH adult males (years)	0.0001	0.0002	0.001**	0.0004**	0.00009
	(0.83)	(1.19)	(4.10)	(2.54)	(0.75)
Max. education of HH adult females (years)	0.0002	0.0005**	0.0002	0.0003**	0.0003**
	(1.19)	(2.33)	(0.90)	(2.06)	(2.36)
Log HH land asset (decimals)	-0.001**	0.0001	0.004**	0.003**	0.002**
	(-2.12)	(0.15)	(3.73)	(3.00)	(2.68)
Log HH non-land asset ('000 Tk.)	0.001**	0.002**	0.004**	0.002**	0.001**
	(2.04)	(3.31)	(3.37)	(3.65)	(4.24)
Village price of fuel wood (Tk./kg)	0.001	-0.0004	0.001	-0.001	-0.001*
	(1.23)	(-0.29)	(0.46)	(-0.78)	(-1.65)
Village price of dung (Tk./kg)	-0.005**	0.006	0.002	0.002	0.001
	(-2.51)	(1.61)	(0.37)	(0.93)	(0.50)
Village price of kerosene (Tk./liter)	-0.001*	-0.001	-0.002	-0.001	-0.0008
	(-1.77)	(-0.74)	(-1.38)	(-1.14)	(-1.57)
Log price of solar home system (Tk./Wp)†	-0.166**	-0.081**	0.027**	0.023*	-0.031*
	(-5.04)	(-1.98)	(0.80)	(1.70)	(-1.93)
Village has primary schools (1=Yes, 0=No)	0.006	0.010	0.022**	0.006	0.006**
	(1.41)	(1.44)	(2.14)	(1.46)	(2.07)
Village has secondary schools (1=Yes,	0.003	0.007*	-0.002	-0.001	0.003
0=No)	(1.20)	(1.89)	(-0.32)	(-0.32)	(1.40)
Village is in *char* land (1=Yes, 0=No)	0.003	0.014**	0.018**	0.009**	0.004
	(1.25)	(2.87)	(2.71)	(2.73)	(1.33)
Village is in a land subject to river erosion	0.002	0.011**	0.012*	0.009**	0.008**
(1=Yes, 0=No)	(0.52)	(2.10)	(1.67)	(2.54)	(2.59)
Village has paved roads (1=Yes, 0=No)	-0.003	-0.001	-0.005	-0.002	-0.001
	(-1.14)	(-0.35)	(-0.72)	(-0.50)	(-0.44)
Village has Grameen Bank (1=Yes, 0=No)	-0.002	-0.002	-0.006	-0.0003	-0.002
	(-0.64)	(-0.45)	(-0.95)	(-0.09)	(-0.77)
Village has BRAC (1=Yes, 0=No)	0.001	0.016**	0.011	0.003	0.005*
	(0.30)	(2.38)	(1.46)	(0.74)	(1.67)
Village has NGOs (1=Yes, 0=No)	0.003	0.005	0.004	0.002	0.002
	(0.65)	(1.07)	(0.37)	(0.37)	(0.76)
Pseudo R^2			0.202		

Note: Marginal effects are reported. Figures in parentheses are t-statistics based on robust standard errors clustered at village level. * and ** refer to statistical significance level of 10% and 5% (or less). Regression includes additional control variables such as availability of various development programs in village and fixed-effects of divisional regions.
Source: BIDS-World Bank survey, 2012.

Table 9: Descriptive statistics of outcome variables of interest

(N=4,000)

Outcome variables	**SHS HHs**	**Non-SHS HHs**	**t-statistics of the difference**
Per capita food expenditure (Tk./month)	1,622.9 (796.0)	1,343.7 (566.7)	6.39
Per capita non-food expenditure (Tk./month)	1,220.4 (2.318.9)	796.4 (1,088.9)	4.79
Per capita total expenditure (Tk./month)	2,843.3 (480.3)	2,140.2 (1,357.0)	6.43
HH kerosene consumption (liter/month)	0.57 (0.89)	2.8 (1.3)	-23.62
Evening study time of boys (5-18) (minutes/day)	131.3 (53.3)	120.0 (49.5)	2.68
Evening study time of girls (5-18) (minutes/day)	127.3 (51.8)	115.0 (48.7)	-2.99
Incidence of gastro-intestinal diseases among boys in last year (5-15) (%)	7.8 (26.8)	6.6 (24.8)	0.56
Incidence of gastro-intestinal diseases among girls in last year (5-15) (%)	8.7 (28.1)	8.1 (27.3)	0.25
Incidence of gastro-intestinal diseases among males in last year (>15) (%)	8.7 (28.2)	9.5 (29.4)	-0.55
Incidence of gastro-intestinal diseases among females in last year (>15) (%)	9.2 (28.8)	9.0 (28.6)	0.13
Incidence of respiratory diseases among boys in last year (5-15) (%)	10.4 (30.5)	12.3 (32.8)	-0.68
Incidence of respiratory diseases among girls in last year (5-15) (%)	10.3 (30.4)	11.7 (32.2)	-0.52
Incidence of respiratory diseases among males in last year (>15) (%)	11.2 (31.5)	10.5 (30.7)	0.39
Incidence of respiratory diseases among females in last year (>15) (%)	8.6 (28.0)	9.4 (29.2)	-0.54
Women’s fuel collection time (hours/day)	0.259 (0.555)	0.386 (0.661)	-2.89
Women’s decision-making ability in household affairs (%)	5.1 (21.9)	3.0 (17.1)	1.94
Women’s freedom in purchasing own goods (%)	17.4 (37.9)	17.6 (38.1)	-0.10

Note: Figures in parentheses are standard deviations.
Source: BIDS-World Bank survey, 2012.

Table 10. Impacts of SHS adoption by the households (p-score weighted regression) (N=4,000)

Explanatory variables	Adoption of SHS	Duration of SHS use (years)	Log consumption of electricity from SHS (kWh/month)
Log HH per capita food expenditure (Tk./month)	0.093*	0.034*	0.091**
	(1.90)	(1.93)	(2.64)
Log HH per capita non-food expenditure (Tk./month)	0.047**	0.020**	0.062**
	(2.09)	(2.41)	(3.98)
Log HH per capita total expenditure (Tk./month)	0.051*	0.021**	0.063**
	(1.84)	(2.06)	(3.10)
Log HH kerosene consumption (liter/month)	-0.683**	-0.327*	-0.688**
	(-30.95)	(-19.71)	(-19.67)
Evening study time of boys (5-18) (minutes/day)	7.0**	2.0*	7.9**
	(2.39)	(1.88)	(3.56)
Evening study time of boys (5-18) (minutes/day)	8.2**	2.7**	8.4**
	(2.71)	(2.65)	(3.29)
Incidence of gastro-intestine diseases among boys (5-15)	-0.006	-0.002	-0.005
	(-0.61)	(-0.56)	(-0.53)
Incidence of gastro-intestine diseases among girls (5-15)	-0.012	-0.005	-0.015*
	(-1.28)	(-1.47)	(-1.72)
Incidence of gastro-intestine diseases among men (16 or older)	-0.013	-0.002	-0.007
	(-1.42)	(-0.69)	(-1.02)
Incidence of gastro-intestine diseases among women (16 or older)	-0.015*	-0.005*	-0.013*
	(-1.66)	(-1.66)	(-1.81)
Incidence of respiratory diseases among boys (5-15)	-0.001	0.0004	0.005
	(-0.08)	(0.08)	(0.55)
Incidence of respiratory diseases among girls (5-15)†	0.001	-0.0005	0.008
	(0.09)	(-0.11)	(0.83)
Incidence of respiratory diseases among men (16 or older)	0.003	0.003	0.006
	(0.33)	(0.77)	(0.85)
Incidence of respiratory diseases among women (16 or older)	-0.012*	-0.002	-0.001
	(-1.64)	(-0.77)	(-0.21)
Women's fuel collection time (hours/day)	-0.090**	0.041**	-0.027
	(-2.11)	(-2.98)	(-0.84)
Women's decision-making ability in household affairs	0.008	0.001	0.013*
	(0.91)	(0.27)	(1.77)
Women's freedom in purchasing own goods	0.003	0.001	0.020**
	(0.26)	(0.31)	(2.22)
Sample mean and standard deviations of intervention variables	0.046†	0.116	0.164‡
	(0.210)	(0.660)	(0.881)

†Mean duration for SHS adopters is 2.5 years

‡Figure is sample mean of household consumption, not of log consumption. Mean electricity consumption for SHS adopters is 3.6 kWh/month.

Note: Figures in parentheses are t-statistics based on robust standard errors clustered at village level. * and ** refer to statistical significance level of 10% and 5% (or less). Regression includes explanatory variables as listed in Table 4.

Source: BIDS-World Bank survey, 2012.