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Quantifying Carbon and Distributional Benefits of Renewable Energy Programs—

The Bangladesh Case Study on Solar Home Systems

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Scaling-up adoption of renewable energy technology—such as solar home systems (SHS)—to expand electricity access in developing countries can accelerate the transition to low-carbon economic development. Using a national household survey, this study quantifies the carbon and distributional benefits of SHS programs in Bangladesh. Three key findings are generated from the study. First, dissemination of SHS brings about significant carbon benefits: the total carbon emissions avoided from replacing kerosene use for lighting by SHS in non-electrified rural households is equivalent to about 4 percent of total annual carbon emissions in Bangladesh in 2007. This figure increases to about 15 percent if grid-based electricity generation is used as the energy baseline to estimate the carbon avoided from SHS installation. Second, SHS subsidies in rural Bangladesh are progressive when the program is geographically targeted. Third, SHS has market potential in many rural areas if micro-credit schemes are made available. The propensity to install SHS is very responsive to income, with a 1 percent increase in per capita income increasing the probability of installing SHS by 12 percent, controlling other factors.

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Introduction

Development agencies place a high priority on providing electricity to over a quarter of the world's population currently without access. This is largely motivated by the increasing recognition of the broad range of economic and social benefits associated with electricity access (World Bank 2002, Wang 2003). Advances in an array of renewable energy technologies—including wind, solar, biomass, and hydroelectricity—present an opportunity for developing countries to increase electricity access while accelerating the transition to low-carbon economic development.

With a range of off-grid options—in particular solar home systems (SHS)[1]—it is possible to provide the basic electricity needs of households, local communities, and small businesses in rural areas where grid-based electricity is not an option in the foreseeable future. The dissemination of SHS over the past two decades has benefited many people in remote areas, providing better quality lighting, enabling extended working hours, and powering small appliances such as mobile phones. These benefits have been achieved with near zero carbon emissions, while also reducing the use of fossil fuels, such as kerosene for lighting and diesel fuel for charging batteries.

Despite technological maturity and the constant decline in SHS prices, the current level of SHS dissemination among rural populations is low. According to the Global Status Report 2009 (REN21 2009), out of the 400 million households who lacked access to grid electricity in 2007, only about 2.5 million received electricity from solar home systems. Scaling up the adoption of low-carbon energy technologies in developing countries must be part of the global effort to reduce the devastating risks posed by climate change. IEA projections suggest that developing countries' share of global carbon dioxide (CO_2) emissions from energy use will increase from 38 percent in 2002 to 52 percent in 2030, while developed countries' share will decline from 60 percent to 47 percent (IEA 2007). Clearly, reducing emissions in developed countries alone will not be sufficient to achieve the goal of limiting the global average temperature increase to no more than 2o C (OECD 2008).

This means that the bulk of the additional investment for climate change mitigation, in particular in the clean energy sector, should flow into developing countries. Following the Bali Action Plan—which calls for mitigation actions by developing countries to be supported and enabled by technology, financing, and capacity building from developed countries—a large number of multilateral and bilateral funds and financial mechanisms such as the Clean Development Mechanism (CDM) were established (Doornbosch and Knight 2008). Rapidly increasing financial resources, both from the public and private sectors, have been channeled into the clean energy sector,[2] thus providing an enormous opportunity to integrate climate change mitigation with economic development.

Maximizing the carbon mitigation and development impact of expanded carbon finance depends on the efficient and equitable allocation of these resources, as well as better implementation of projects through targeting and coordination with poverty projects. Renewable energy programs—in particular dissemination of solar home systems—have been implemented by international institutions and NGOs in many developing countries over the past two decades. But few studies have employed large-scale household surveys to quantify the carbon benefits and the distributional impact of SHS programs. This study aims to fill this gap by using the first available national household survey that collects SHS installation data in rural Bangladesh, which is one of a few countries that have made significant progress in providing electricity access to rural people through the installation of solar home systems.[3] It focuses on (1) the quantification of the carbon benefits, particularly on kerosene displacement; (2) SHS affordability; and (3) the distributional consequences of SHS subsidies.

Rural electrification and the SHS program in Bangladesh

While Bangladesh has made impressive progress in expanding rural electrification, its electrification rate still lags behind other countries in South Asia. Between

2000 and 2008, the rural electrification rate increased by only about 8 percentage points—to 28 percent. By comparison, South Asia experienced an increase of 18 percentage points—to 48 percent—over the same period (Figure 1).

The Bangladesh government has set a target of providing the entire country with electricity by 2020, with improved reliability and quality of electricity supply. However, achieving this target requires effective measures that can overcome two major constraints currently facing the electricity sector. First, while per capita electricity generation capacity in Bangladesh is among the lowest in the world (at about 165 KWh per year), the demand for electricity is growing at a rate of over 500 MW per year due to population growth, the rapid increase in demand for electrical appliances, and industrialization. As a result, power outages are common occurrences.

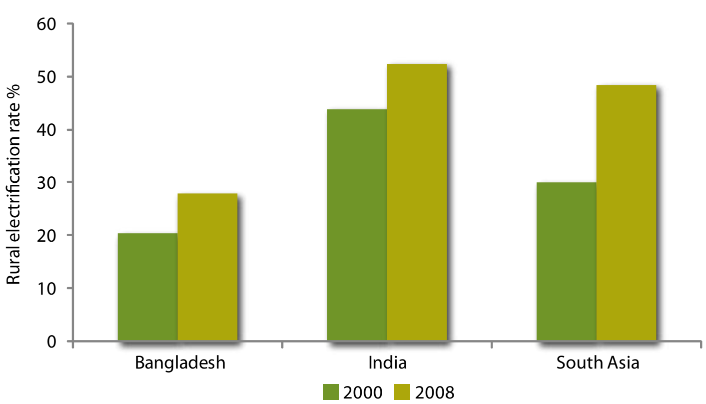
Second, the majority of the rural population lives in areas that are distant from the national electricity grid. Even if these households were connected to the grid, insufficient generation capacity would lead to disproportionate load shedding in rural areas. Realizing that grid electrification is not an economically feasible option, the government has taken a dual-track approach to expanding rural electrification: (1) expanding the electricity distribution grid to connect new consumers, and (2) making solar home systems available to households and promoting biomass projects to electrify village markets and small enterprises (World Bank 2009).

A World Bank project—Rural Electrification and Renewable Energy Development (RERED)— started in 2002 with total funding of $298 million and aims to expand rural electrification through both grid extension and renewable sources. The project's success, in particular with the dissemination of solar home systems in rural areas, had led to a request from the government for additional financing of $130 million in 2009, with $100 million earmarked for scaling-up SHS installation and other renewable-energy-based mini-grids in rural areas. The implementation of SHS programs was carried out using two different delivery models. The first model was implemented by the state-owned Rural Electrification Board (REB). It disseminated SHS through a fee-for-service program, whereby the system would be installed and owned by REB and households would pay a monthly fixed fee for using the system. The second approach is through a private agency, the Infrastructure Development Company Limited (IDCOL), which received financial support from GEF to implement the dissemination of solar home systems through various private agencies, such as Grameen Shakti, using a micro-finance scheme.[4]

While REB was able to provide solar home systems for about 12,000 households, IDCOL reached over 320,000 households over the same period (accounting for about 1.6 percent of non-electrified rural households). The success of the micro-credit scheme by the private sector in SHS dissemination lies mainly in the fact that these private delivery agencies, in particular Grameen Shakti, have more practical knowledge in providing micro-finance and greater reach at the community level (Asaduzzaman and others 2008).

The key lessons from the Bangladesh experience is that while scaling-up the adoption of renewable energy technology depends critically on private sector participation, public support is critical at

Figure 1. Rural electrification progress, 2000–08



the initial stage, in particular financing. Lessons from the Bangladesh case study can possibly be transferred to other countries while taking account of local conditions.

Carbon benefits, affordability, and distribution impact of RERED

A nationally representative household survey was collected in 2005 for monitoring and impact evaluation of the RERED project. The survey collected information on 20,913 households from 6 divisions, 47 districts, 268 subdistricts (i.e., Upazila), and 1,350 villages in rural areas, including 1,000 households that had purchased solar home systems under the financing scheme, which provides a micro-credit loan and cash subsidies to households living in non-electrified villages. This survey data provides an opportunity to (1) quantify the carbon benefits, (2) assess SHS affordability, and (3) analyze the distributional consequences of SHS programs.

How much CO_2 emissions can be avoided from SHS?

The total amount of CO_2 avoided depends on how much kerosene consumption is displaced due to SHS installation. The United Nations Framework Convention on Climate Change procedure defines the fuel consumption of the technology/device in use (or that would have been used) in the absence of project activity as the energy baseline for the quantification of carbon benefits of renewable energy projects (Ybema and others 2009). The impact of SHS on kerosene displacement is estimated using the propensity score matching method, which controls confounding factors such as income, household size, and location effects. The results show that, on average, about 2.7 liters of kerosene are displaced per SHS per month, after controlling for household socioeconomic factors.[5] The scale of kerosene displacement increases with household income: about 2.3 liters per month for the bottom two income groups, and 3 liters per month for the top two groups, holding other factors constant.

Using the carbon emission factor for kerosene (2.45 kg CO_2/liter), the avoided CO_2 emissions for the most commonly purchased solar home system (40–50 Wp) is about 76 kg CO_2 per year in the context of rural Bangladesh. The estimate from the Bangladesh survey is significantly smaller than estimates obtained from other sources, as summarized in Table 1. This is possibly due to two factors: (1) the estimate for Bangladesh controls for confounding factors; and (2) the Bangladesh study focused only on kerosene; it did not include diesel and dry cells due to data limitations of the survey.

While displacing kerosene use for lighting and diesel for battery charging are the most direct carbon benefits, SHS dissemination can also avoid emissions from new electricity connection through fossil-fuel-based electricity generation (Kaufman and others 2000). This is particularly applicable in the context of Bangladesh, where the government has determined to use SHS as one of the alternatives to the grid option in its efforts to achieve the target of universal access to electricity by 2020. Using grid-electricity generation as the energy baseline, the carbon emissions avoided from SHS are equivalent to about 269 kg CO_2 per SHS per year, which is about 3.5 times that estimated using the kerosene displacement baseline.

The scale of the carbon emissions avoided from SHS adoption can be better illustrated by putting these estimates in the national context of the total number of households currently without electricity access (about 24 million households in Bangladesh in 2008, according to IEA statistics). If all non-electrified households were provided with solar home systems, the carbon emissions avoided from kerosene displacement per SHS per year would be equivalent to about 4 percent of total annual carbon emissions in Bangladesh in 2007. This figure will go up to about 15 percent if grid-based electricity generation is used as the energy baseline to estimate the annual carbon benefit from SHS.[6]

Is scaling-up SHS possible in rural Bangladesh?

The cost of SHS is significant relative to household incomes in rural Bangladesh. The price of the most

TABLE 1. Summary of estimates of CO_2 emissions avoided per SHS per year			
Country	*Founding scheme SHS model*	*SHS model (Wp)*	*Emissions reduction (kg CO_2/yr)*
Argentina	Global Environment Facility	50–400	504
Honduras	Activities implemented jointly	30–60	246
India	Commercial carbon offset funding	20–53	373
Indonesia	World Bank/GEF	50	448
Nepal	Government of Nepal	35	79
Kenya	Commercial cash sales	12–50	205
South Africa	Shell/Eskom fee for service	50	230
Swaziland	IVAM/ECN triodos commercial credit	50	125
Bangladesh	World Bank/GEF	25–85	76

Note: The Bangladesh figure is estimated using the 2005 household survey, but all other studies are not survey-based estimates.
Source: Ybema and others 2000.

commonly installed system with a 40–50 Wp capacity was about $556 in Bangladesh in 2002, which was more than three times the average rural household's annual expenditure. Therefore, the major barrier for SHS adoption is the large up-front cost. If micro-credit schemes are made available, SHS is likely to be an attractive option to many households in rural areas, given that grid electrification is unlikely to be an option for many years to come.

We assessed the affordability of SHS using the average energy budget share as the benchmark. A budget share of 8 percent, which is estimated based on the existing micro-credit schemes, was used to define affordability. That is, households are able to afford SHS under the existing micro-credit scheme if their budget share for monthly SHS financing is below the level of 8 percent. Admittedly, this level of budget share is high, so the estimated affordability rate should be regarded as an upper-bound estimate. Under this criterion, the total number of households in rural areas that can afford SHS is about 76,000 households under the existing micro-credit scheme, plus a $50 cash subsidy representing about 24 percent of non-electrified households in the sample districts. This number goes up to about 45 percent if the cash subsidy increases to $90.

The spatial analysis also shows that there is market potential in many rural areas to scale up SHS adoption. Among the 42 districts in the sample, 17 districts have an affordability rate above 25 percent, as well as a relatively high proportion of households living in non-electrified villages; the average is about 45 percent among the 17 districts, compared to the national average of 38 percent. The econometric analysis shows that the propensity to purchase SHS is very sensitive to household incomes, with a 1 percent increase in per capita expenditure increasing the probability of installing SHS by about 12 percent, holding other factors constant.

Are SHS programs progressive?

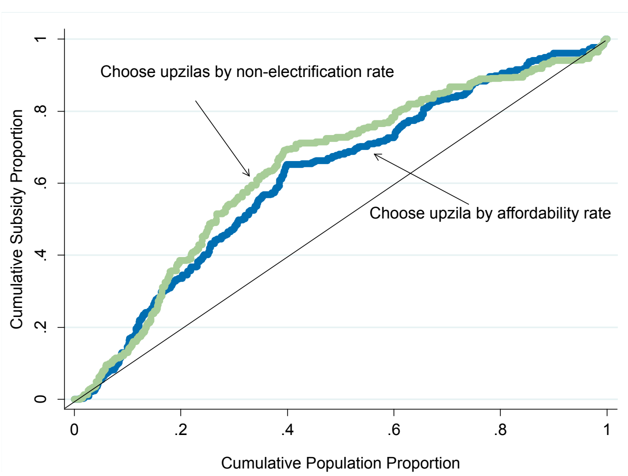
The general belief based on anecdotal evidence is that SHS subsidies are not pro-poor because better-off households disproportionately capture the subsidies. Consequently, expanding rural electrification from SHS dissemination is often not considered to be an effective policy choice for addressing poverty issues, although little empirical evidence exists to validate such claims. The Bangladesh national survey data present an opportunity to empirically assess the distributional impact of SHS programs.

The distributional consequences are illustrated using a policy simulation exercise under two assumptions.

First, all households currently without grid electricity are assumed to be entitled to the micro-finance scheme. Second, the private sector agencies who are responsible for SHS dissemination decide program locations at the upzila level. The choice of location is driven by the objective of maximizing SHS dissemination while minimizing operational cost. Two indicators that are important from the perspective of delivery agencies include (1) the affordability rate, and (2) the proportion of households living in villages without grid electricity, both capturing the market potential of SHS as well as the scale of the operational cost. The distributional consequences are essentially determined by the location choices of the private sector delivery agencies.

The distributional impact of the SHS program is analyzed using the concentration curve, which plots the cumulative percentage of SHS subsidies received by households against the cumulative percentage of household population, ranked by per capita income in ascending order.7 Figure 2 shows that targeting SHS programs based either on affordability rate or the proportion of non-electrified households will be progressive. As expected, the location choice based on the latter is more equitable, with the bottom 30 percent of households receiving about 55 percent of total subsidies, while they only receive about 45 percent if the targeting is based on affordability rate. The positive distributional consequences result mainly from the strong spatial correlation between the concentration of non-electrified households and the poverty rate, as shown in Figure 3.

Figure 2. The distributional impact of location choices



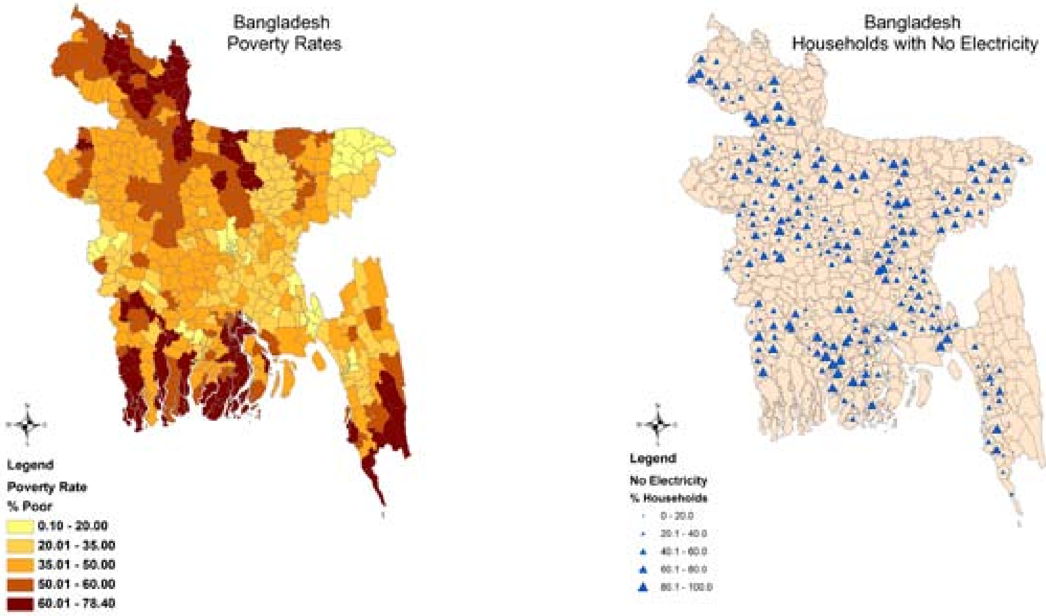
This finding indicates that targeting, as well as better integration of renewable energy projects with existing development projects at the local level, is critical to enhancing the synergies between carbon mitigation and development. For example, placing SHS programs in localities where the affordability rate is sufficiently high and where poverty alleviation programs are in place can avoid duplication, while maximizing the impact through resource pooling and coordination. With the rapid increase in carbon finance for climate mitigation projects in developing countries, policy makers should now focus on how renewable energy projects should be targeted and integrated with poverty programs.

Conclusions and policy messages

Using the Bangladesh national household survey, this study provides three key findings. First, dissemination of SHS for rural electrification can generate substantial carbon benefits in the context of rural Bangladesh. The annual carbon avoided from kerosene displacement as a result of SHS installation would be equivalent to about 4 percent of total annual carbon emissions in Bangladesh in 2007 if all non-electrified households were provided with solar home systems. This figure will go up to about 15 percent if grid-generated electricity is used as the energy baseline to estimate the carbon benefit from SHS.

Second, under the assumption that the existing micro-credit scheme plus a cash subsidy is made available to all non-electrified households in rural Bangladesh, the affordability assessment indicates that scaling-up SHS adoption is possible in many rural areas. Among the 41 districts in the survey, about 17 districts have an affordability rate over 25 percent, as well as a high concentration of non-electrified households in comparison to the national average. This means there is a potential market for solar home systems. It is also possible to reduce the

Figure 3. Upzila level poverty and non-electrification rates in Bangladesh



costs of SHS dissemination due to economies of scale to promote profitable participation of the private sector in the SHS market.

Third, contrary to the commonly held view that subsidies to promote SHS dissemination in rural areas benefit mainly better-off households, our policy simulation shows that SHS subsidies in rural Bangladesh are progressive when programs are targeted to localities based either on the affordability rate or the concentration of non-electrified households.

Two policy messages emerge from this study. First, the Bangladesh experience shows that while the potential for scaling up SHS in rural areas exists if the up-front cost of SHS can be addressed through improving access to micro-credit in combination with cash subsidies, the real challenge lies in how these programs can be implemented on the ground. The success of SHS dissemination in rural Bangladesh depends critically on active policy support, in particular at the initial stage of the operation. This support should include financing, technical assistance, SHS information dissemination, and the development of institutional capacity and human resources at the community level.

Second, the rapid increase in financial resources channeled to climate mitigation, in particular in the clean energy sector, presents an opportunity to integrate renewable energy projects with development projects to reinforce synergies between climate change mitigation and development. This means that efforts must focus on improving the efficient and equitable allocation of carbon finance to projects that generate the largest carbon and development benefits. At the project level, the design and implementation of renewable energy projects should focus on key issues—such as targeting, integration, and coordination with poverty alleviation programs—in order to maximize the carbon mitigation and development benefits.

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Endnotes

1. A typical SHS that consists of a PV module with a 20-year life cycle, a controller, and a rechargeable lead-acid battery can be easily manufactured to good quality standards in many countries. The price has been declining rapidly over the past few years; the average price for a 40–50 Watt peak system (Wp) is about about $200–$300.
2. The World Bank Group has seen a steady increase in the share of energy sector financing committed for low-carbon renewable energy and energy efficiency, rising to about 40 percent in 2007 from 13 percent in 1990–94. By 2007, about 650,000 solar home systems had been installed across 23 countries.
3. The Bangladesh SHS programs that were financed by the Global Environment Facility (GEF) and International Development Association (IDA) had installed over 300,000 solar home systems (about 1.6 percent of rural households without electricity) in rural areas by 2009.
4. Under this scheme, households were provided with a loan for a period of 4–5 years, at an annual interest rate of 12 percent, plus a $50 cash subsidy. Households who received the loan were required to make a down payment of 10 percent of the total cost of the system.
5. The estimated reduction is 3.9 liters/month from a smaller scale household survey (441 households) conducted by Grameen Shakti in 2009. Chaurey and Kandpal (2009) provide an estimate of 9.6 liters/month for rural households in India, and the World Bank project report finds 19.6 liters/month displacement for rural households in Indonesia.
6. The above estimated carbon benefit is not measured in terms of life cycle emissions.
7. If the concentration curve (CC) lies above the 45 degree line of equality, the allocation of subsidies is progressive, with the poor households capturing the total subsidies disproportionately, and vice versa if it lies below the equality line. The CC can also be used to compare different policy options. If one CC lies everywhere above another one, the first curve is said to dominate the second one, in the sense that the first curve represents a more progressive policy option than the second one.