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Social benefits of solar energy: Evidence from Bangladesh

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Abstract

Research background: The Bangladeshi government has set a plan to generate one-tenth of its electricity from solar and other renewable sources by 2030. Solar adoption surged in Bangladesh up until 2015, setting a global precedent for electrifying areas that were previously unconnected. The enhanced lighting offered by solar systems provides immediate benefits, including additional hours for household and business activities and extended study hours for school-going children.
Purpose of the article: This study seeks to identify the determinants and welfare gains of solar adoption in rural areas by analysing three rounds of the Bangladesh Integrated Household Survey from 2011–12, 2015, and 2018–19. In addition to presenting new estimates of economic, environmental, and educational welfare gains, our research offers insights into how solar adoption relates to rural employment and the nutrition of children under five.
Methods: We utilized both ordinary least squares and propensity score matching techniques to estimate the welfare effects of solar adoption. Only households that do not use electricity as their primary lighting source, such as those relying on solar or kerosene, are considered in our sample.
Findings & value added: We have discovered that adopting solar is linked to higher income, increased expenditure, and growth in asset value. Additionally, there is a significant reduction in kerosene expenditure among adopters compared to non-adopters. Other observations reveal that households with solar setups tend to transition from sharecropping to trading and poultry farming. Children in these households also benefit from solar adoption in terms of education and nutrition. This study illustrates how solar energy can effectively address various welfare concerns in areas where the government cannot supply electricity. Given that recent global events have rendered underdeveloped countries more vulnerable to providing consistent electricity to their entire populations, this research suggests solar energy as a resilient electrification solution during crises.

Introduction

Developing countries' ability to achieve universal electrification is limited by electricity generation and its inability to distribute sufficient grid electricity to fulfil the demand. As a result, renewable energy is recognized as one of the technological revolutions and is widely viewed as a more practical alternative for electrifying rural houses or isolated areas in developing countries where grid extension is infeasible. Even if households in developing countries have access to grid connections, they experience frequent power outages that last for more extended periods (Khandker *et al.*, 2014b). In such a situation, solar might not only be a solution for non-electrified households, but individuals can also use it as a hybrid solution (i.e., both grid and solar) to secure a continuous flow of electricity against power outages. In addition, solar can be thought of as an urban solution, in regions of frequent power outages. Therefore, the Bangladeshi government plan to generate one-tenth of electricity from renewable sources by 2030, according to the Sustainable Development Goals Bangladesh Progress Report (Bangladesh Planning Commission, 2022).

Improved lighting through solar systems provides immediate benefits at the household level. It starts with extra hours of household activity and extended study hours for school-aged children. In addition, people get recreational and educative information and knowledge from television, radio, and cell phones and work longer hours in income-generating activities. Solar electrification also brings health and environmental benefits as well. For instance, solar home systems (SHSs) serve as an income-generating catalyst for rural households (Best & Chareunsy, 2022; Buragohain, 2012; Sharif & Mithila, 2013). SHSs have raised household living standards, particularly for women, and increased children's study time (Komatsu *et al*., 2013; Mishra & Behera, 2016). Solar energy has benefitted the environment by lowering indoor pollution caused by traditional energy sources such as kerosene (Cabraal *et al*., 2021; Mishra & Behera, 2016).

Despite the significant body of literature focusing on the implications of on-grid electrification, few studies have analysed the impact of solar adoption on the livelihood and welfare of rural Bangladeshi people. Khandker *et al*. (2014b) are the most important in this context. They used cross-sectional data collected by the Bangladesh Institute of Development Studies and the World Bank in 2012. We applied the recently published third round of the Bangladesh Integrated Household Survey (BIHS) (2018–2019) (IFPRI, 2020) with the other two rounds (2011–2012 and 2015) (Ahmed, 2013; IFPRI, 2016) to estimate the benefits of solar power adoption. This study focused on the three dimensions of the United Nations Development Programme’s Human Development Index: economic, educational, and health. In addition, we assessed environmental outcomes and the gender-disaggregated change in employment dynamics among rural people because of solar adoption. Therefore, the study’s goal is to identify the factors that are playing a role in solar adoption and the effect of solar adoption on the household’s economic, occupational, and environmental outcomes, and children’s educational and nutritional status in Bangladesh.

The study presented in this paper offers three key contributions. First, it illuminates the relationship between solar adoption and the employment structure in rural areas. Second, it elucidates the link between solar electrification and the nutritional outcomes for children under five. Lastly, it presents fresh estimates on economic, environmental, and educational outcomes using three waves of BIHS data.

This study has found that the education of the head of the household, wealth status, number of households, log of total land holdings, presence of sanitary latrine, and remittance holder in the household are positively associated with solar adoption, whereas the male head of a household and electrification status of the community have a negative impact on solar adoption. For welfare analysis, both the propensity score matching (PSM) and ordinary least squares (OLS) estimates indicate that solar adoption positively impacts income, expenditure, asset formation, children's education, and health. Additionally, solar adoption reduces the reliance on dirty fuels and boosts the usage of gas and liquefied petroleum gas (LPG). Furthermore, solar electrification is linked to shifts in the rural employment structure. It reduces reliance on sharecropping and encourages alternative forms of self-employment, such as trading for men and poultry farming for women.

The remainder of the paper is organized as follows. Section two delves into the literature concerning the welfare gains from solar adoption. Section three outlines the conceptual connection between solar adoption and welfare outcomes as presented in this paper. Section four is dedicated to the methods, data, and some preliminary bivariate results. Section five presents the main findings and associated discussions. The conclusion of the study is presented in the sixth section.

Literature review and conceptual framework

This section highlights the important aspects that influenced the adoption of SHS in various countries and how it impacts individuals' lives from different works of literature. The welfare gain from solar electrification was then divided into some categories to get a clear picture. These include how it enhances families' economic and social outcomes. Also, how the SHS contributes to children's and women's lives. Furthermore, it includes how solar adoption could be linked to five dimensions of human development and wellbeing: economic, employment, environmental, education, and health/nutrition.

Solar adoption and satisfaction

A range of social, economic, demographic, and institutional factors, including the government's approach to rural electrification, influence households' adoption of solar energy. One meta-analysis reports that the most important factor in determining adoption intention is perceived advantages (Schulte *et al.*, 2022). In addition, there are other factors playing a critical role in solar adoption, such as environmental and economic (Jacksohn *et al.*, 2019). For instance, economic reasons are more important for solar adoption among Australian households (Zander, 2020) and kerosene consumption, indoor pollution concerns, and the necessity for electric lighting are more valuable in Bangladesh (Komatsu *et al.*, 2011).

On the other hand, Best *et al.* (2021), show that financial assets are more essential than income and nonfinancial assets for a household's solar adoption. Similarly, flexible payment options rank among the most important determinants for SHS uptake in Uganda, along with factors like income, residence, and house structure (Aarakit *et al.*, 2021). Apart from households, a study on Mexican businesses reveals that the adoption of solar panels is influenced by business type, ownership status, and appliance usage (Hancevic & Sandoval, 2023).

Even though the people's overall impressions of solar power are good, they have low trust in local solar enterprises in India because of poor product quality and service (Urpelainen, 2016). In Bangladesh, user satisfaction is negatively influenced by previous unsatisfactory experiences with the frequency of battery repairs and parts replacements. Reduced dependency on kerosene and extended hours of children's study time, on the other hand, reward homes with increased consumer satisfaction (Komatsu *et al.*, 2013). According to the Sri Lankan experience, providing solar system maintenance training by service workers improves user satisfaction (Wijayatunga & Attalage, 2005).

Solar and economic outcome

Solar uptake might be economically beneficial as individuals are allowed work longer hours in improved lighting environment. For instance, it influenced economic productivity in Kenya (Jacobson, 2007), enabled people to open new businesses in India (Buragohain, 2012), and improved productivity of existing enterprises in rural Kenya (Pueyo & DeMartino, 2018). According to Mishra and Behera (2016), fishermen can perform fishing for longer hours in rivers and seas and earn more than before adopting the solar system. Similarly, it is found that solar system ownership increases the financial return by 300% in USA (Crago *et al*., 2023), and large-scale solar infrastructure intervention by government also enhance poor people's income in China (Liao *et al*., 2021).

In the case of Bangladesh, solar system adoption increased spending by about 4%, whereas raised income by up to 12%. An additional year of solar usage raised household per capita income by about 3% and per capita spending by roughly 2% (Khandker *et al*., 2014a). Other studies also found SHS as an income-generating catalyst in the Bangladeshi rural communities (Sharif & Mithila, 2013) whereas some studies found that the income effect is negligible (Rahman & Ahmad, 2013)

Solar and environmental outcome

Solar home-lighting systems directly impact kerosene usage for lighting. It had significantly reduced kerosene consumption in Indian (Buragohain, 2012) and in Kenya (Wagner *et al*., 2021). According to Khandker *et al*. (2014b), solar system adopters decreased kerosene usage by more than 2 litres per month compared to non-adopters. In addition, for every additional year of solar use, kerosene use lowers by 0.71 litres per month.

Between 2003 and 2018, the World Bank's solar project in Bangladesh decreased roughly 9.6 million tons of GHG emissions and avoided the consumption of 4.4 billion litres of kerosene (Cabraal *et al*., 2021). However, the toxic chemicals used in the production of solar panels and batteries can harm the environment if not properly disposed of after their useful life has ended (Khan, 2019).

Solar and child education

The enhanced light from solar provides longer study hours and better study environment for children. For instances, children used to go to bed early because of a lack of light, which hampered their educational outcomes (Mishra & Behera, 2016), and adoption of SHS increased around 30 minutes of daily lighting in Kenya (Wagner *et al*., 2021). It also improved school-aged children's educational performance in India (Buragohain, 2012). In addition, children are also available for performing household chores as they can study at night.

In the case of Bangladesh, solar adoption boosts children's nighttime study time (Samad *et al*., 2013) and children's years of schooling and school enrolment (Khandker *et al*., 2014a). Utilizing solar energy could, therefore, have long-term advantages in addition to enhancing educational chances for the current generation.

Solar and health outcome

Children directly benefit from clean lighting sources like solar by being exposed to less indoor smoke from kerosene lamps while studying. Additionally, it may have long-term consequences for females and children who often spend a lot of time indoors.

According to Obeng *et al.* (2008), using SHSs in rural Ghana reduced nearly half of the indoor smoke and one-third of the blackened nostrils caused by kerosene lamp soot among household members. Reducing kerosene usage lowers the morbidity of women and children from respiratory disorders (Samad *et al*., 2013). However, when lead-acid batteries reach the end of their useful lives, poor disposal and recycling may result in landfill contamination with lead sulphate which might create health hazards (Khan, 2019)

Research concept

The transition to renewable energy causes systemic changes in economies and society, which eventually have an influence on households. They might gain from solar adoption through five dimensions: economic, employment, environmental, education, and health/nutrition. Adopting solar energy benefits households with enhanced lighting, leading to three immediate gains: enabling productive night-time work, replacing dirty fuels such as kerosene, and fostering a better study environment. With the ability to complete their domestic work at night, women can now also engage in self-employment or hired labour. Meanwhile, men can utilize their spare time for non-farm business activities, such as operating part-time shops and pursuing other trading activities. As a result of these activities, their employment and income may increase, which will allow them to eat better food and make more investments in the human capital building, such as raising their spending on health care and education.

Additionally, solar lighting, being more effective than traditional kerosene lamps, directly reduces the reliance on dirty fuels. This transition away from kerosene leads to immediate benefits such as improved indoor air quality and fewer challenges associated with managing conventional lamps. These benefits don't stop at lighting. For example, families that adopt solar energy often transition away from traditional cooking fuels, like firewood, coal, cow dung, and dried leaves. They opt for cleaner alternatives like gas or LPG, reducing both indoor and outdoor pollution. This shift helps mitigate various respiratory and gastrointestinal conditions linked to the emissions from traditional fuels.

Moreover, solar electrification allows families to watch television and access social media on their phones, granting them insights into news, hygiene practices, and health-related information. This knowledge can empower mothers in nurturing and ensuring the well-being of their children. Furthermore, if solar adoption enhances a household's economic status, it can lead to better nutritional choices for children, reducing issues like stunting and underweight.

Research methods

This study aimed to find both determinants and welfare gains of solar adoption. At first, we used both the ordinary least square (OLS) and the Probit regression (marginal effect) to determine which factors are responsible for adopting SHS. In this case, the dependent variable is the solar adoption status. If a household i's solar adoption is defined by $s_{it} = 1$ and 0 otherwise, then the model is

$$s_{it} = \gamma X_{it} + u_{it} \tag{1}$$

$$Pr(s_{it} = 1|X_i) = \varphi(\beta X_{it} + \varepsilon_{it}) \tag{2}$$

where X_{it} represents the demographic, economic, and community-specific characteristics, γ's and β's are the coefficients of each explanatory variables, $\boldsymbol{\varphi}$ is the the cumulative distribution function (cdf) and $\boldsymbol{u_{it}}$ *and* $\boldsymbol{\varepsilon_{it}}$ are the error terms. We reported the marginal effect of the probit model in the result.

As we could not find a proper instrumental variable for measuring the welfare effect of solar adoption by households, we employed the OLS and PSM techniques. As we are using three waves of the BIHS, we estimated both years based on cross-section results and pooled regression results (i.e., two or all three survey waves). In addition, the standard errors are clustered at the village level, which is robust for both the heteroscedasticity and correlation within entity overtime. We estimated the following OLS model:

$$Welfare_{it} = \beta_0 + \beta_1 (Solar)_{it} + \beta_2 \text{ (Demographic)}_{it} + \\ + \beta_3 \text{(Economic)}_{it} + \beta_4 \text{(Community)}_{it} + u_{it} \quad (3)$$

where i represents the individual respondents, t stands for time (i.e., 2011–2012, 2015, and 2018–2019), β_0, β_2, β_3, and β_4 are the intercept, coefficients of demographic, economic and community variables, respectively, and u_i is the error term. The coefficient of solar (β_1) gave us the idea of the degree of association between welfare outcome and solar adoption. The specific welfare equations are as follows:

$$\text{Economic}_{it} = \beta_0 + \beta_1 (Solar)_{it} + \beta_2 (Demographic)_{it} + \\ + \beta_3 (Economic)_{it} + \beta_4 (Community)_{it} + u_{it}$$

$$\text{Employment}_{it} = \beta_0 + \beta_1 (Solar)_{it} + \beta_2 (Demographic)_{it} + \\ + \beta_3 (Economic)_{it} + \beta_4 (Community)_{it} + u_{it}$$

$$\text{Environment}_{it} = \beta_0 + \beta_1 (Solar)_{it} + \beta_2 (Demographic)_{it} + \\ + \beta_3 (Economic)_{it} + \beta_4 (Community)_{it} + u_{it}$$

$$\text{Education}_{it} = \beta_0 + \beta_1 (Solar)_{it} + \beta_2 (Demographic)_{it} + \\ + \beta_3 (Economic)_{it} + \beta_4 (Community)_{it} + u_{it}$$

$$\text{Nutrition}_{it} = \beta_0 + \beta_1 (Solar)_{it} + \beta_2 (Demographic)_{it} + \\ + \beta_3 (Economic)_{it} + \beta_4 (Community)_{it} + u_{it}$$

Cross-sectional comparisons between solar-electrified and non-electrified households are likely to produce biased estimates when calculating the effects of solar electrification. This is because these households may differ in different aspects and not be similar to each other. Thus, we applied PSM, precisely the nearest neighbour approach. We utilized the statistical software STATA to estimate the model parameters.

Outcome and control variables

The presence of SHS in a house was the primary variable of interest, and we saw how SHS affects economic, self-employment, environmental, educational, and nutritional outcomes. We also analysed the gender-based dimension for some of these outcome variables in some cases. Economic and environmental outcomes are measured at the household level, whereas employment, educational, and nutritional outcomes are measured at the individual level.

The economic outcome includes income, expenditure, and household/agricultural asset ownership status of households. While calculating employment outcomes, we excluded the young, students, retired, too old, and disabled members of a family and those who think they do not need to work. We believe that solar adoption could affect self-employment in the short run. Therefore, we include self-employment variables such as farm and non-farm work (i.e., poultry and trading business). In the case of the environmental outcome, we took the use of dirty (i.e., kerosene and agro-fuel) and clean fuel (i.e., gas/LPG) use status of the household. We adjusted the monetary data for inflation (i.e., with Consumer Price Index data published by the Central Bank of Bangladesh).

Years of education are calculated based on students' completed years of schooling. In the case of secondary enrolment, in Bangladesh, secondary education starts at grade 6 and continues up to grade 10. Students aged 11 generally enter secondary school. Thus, we calculated secondary enrolment for 11 year-olds or more students. In this study, we have calculated monthly education expenditure per student, including the textbook, annual/monthly school fee, examination fee, personal teaching expenses, stationery, and hostel expenses. While calculating the cost, we only took the school-enrolled students.

The nutritional outcomes are measured through the height-for-age z-score (haz) for stunting and weight-for-age z-score (waz) for underweight following WHO standards for under-five children and then categorized as such as mild (haz/waz<-1), moderate (haz/waz<-2), and severe (haz/waz<-3).

In addition, we controlled demographic, economic, and community-specific variables. Definitions of all control variables are listed in Table 1.

Data

This study covers three rounds (2011–2012, 2015, and 2018–2019) of the BIHS conducted in rural areas representing the whole of Bangladesh. BIHS is not just representative of rural Bangladesh nationwide, but also of rural areas in each of the country's seven administrative divisions. The BIHS covers a total of 18,604 households in three rounds, including 6,500 households both in 2011–2012 and 2015, and 5,604 households in 2018–2019 (Ahmed, 2013; IFPRI, 2016, 2020). However, those households that do not use electricity as their primary lighting source (such as solar and kerosene) are only included in our analysis.

Bangladesh has taken massive electrification projects to electrify every house within 2021 and, therefore, the number of non-electrified houses considerably decreased between 2011 and 2019. As a result, a larger number of households are dropped for the recent surveys, and we fail to form a panel of household who are without electricity in all the survey waves. Finally, 6,712 pooled households (either electrified by solar or do not have any electric connection) are considered for analysis. Among them, 3,340 households from 2011–2012, 2,608 from 2015, and 764 from 2018–2019. As a result, we provide both cross-section and pooled (i.e., two or all three survey waves) estimates in the result section. The descriptive statistics of data are presented in Table 2.

The association between the outcome variables and SHS adoption status is tested by mean comparison two-sample t-test and shown in Tables 3–7. Economic and environmental outcomes are highly correlated with solar adoption all their rounds. This implies that solar adoption is associated with increased income, expenditure, asset value, harvest value and clean fuel use and decreased kerosine and other dirty fuel use. Educational outcomes are also highly associated with solar adoption for the first and second rounds of data. Solar electrification significantly reduces the prevalence of different levels of stunting and underweight, but not for all categories. However, the occupational outcome is not that much associated, but it gives a clear message that male members are more involved in the trading business and women members are doing poultry farming in the SHS houses.

Results

Factors influencing the solar adoption

Several socioeconomic and demographic factors play crucial roles in adopting solar. As solar adoption is a dichotomous variable (where one (1) represents solar adoption and zero (0) otherwise), we saw both the ordinary least square (OLS) and the marginal effect of the probit model (Table 8). We have found that the education of the head of household, household size, amount of land, remittance-receiving house, loan taker, and wealth are positively associated with solar adoption. However, the male head of household, community electrification status, percentage of households with electricity, and concrete roads within the community negatively influence solar adoption.

These results indicate that solar adoption is decreasing among electrified villages and areas where a higher proportion of households have electricity. We also found that one community-specific variable (i.e., concrete road within the community) is also negative in the probit estimate and others are insignificant. These findings may explain why solar installations and the proportion of renewable energy and electricity in Bangladesh are declining. Another explanation could be the government's high priority to electrify every house within 2021, which forced them to connect villages with the national grid.

The effect of solar electrification on economic outcome

Both OLS and PSM analyses show that solar adoption had increased the total expenditure and household asset value for all three survey years and increased income, food, and non-food expenditure for most cases (Table 9). However, the increase in household asset value (100% based on PSM three-round pooled estimate) is higher than both income (20%) and expenditure (15%). Khandker *et al.* (2014a) also found a similar effect for Bangladesh. However, solar enhance economic outcomes with a greater magnitude in this study. The reason might be that the SHS installation increased at a moderate pace up to 2015 and it takes some time to realize the benefit. As we used three waves of data ranging from 2011 to 2019, our analysis might cover most of the welfare benefits received by the household, whereas the analysis of Khandker *et al.* (2014b) is based on cross-section data collected in 2012.

The effect of solar electrification on employment outcome

Our analysis found a negative relationship between solar adoption and sharecropping activity among males and females in solar-adopter households (Table 10). That is, males and females in solar adopter households might leave the sharecropping activity compared to non-solar households. Among solar adopters, males are more associated with the trading business, including roadside stalls or shops, wholesale shops, fish trading, and contractor. Females are more correlated to work in the poultry business. In our three-wave pooled analyses, OLS estimates show that 3% of males and females in SHS households left sharecropping. In contrast, the PSM estimates indicate that about 4% of males left the sharecropping activity. According to PSM estimates, about 3% of the males in SHS households are involved in trading businesses, and 8% of females are involved in poultry-raising businesses.

For robustness check, we also applied the multinomial model in the appendix (Table A1), as the employment categories are unordered categorical variable. We check the association between solar adoption and employment with and without adjusting the controls and found to some extend similar results as original, which confirms the relationship.

The effect of solar electrification on environmental outcome

Solar adoption directly reduces use of dirty fuel like kerosene as it is a direct substitute to produce light. On the other hand, households might realise the benefit not using kerosene and get influenced to reduce the use of dirty cooking fuels. Table 11 shows that SHS households reduced kerosene expenditure by about 155% in 2011–2012, 210% in 2015, and 215% in 2018–2019. In our three-round pooled estimates, the kerosene expenditure lessens by around 200%. Moreover, the expenditures on agri-fuel such as paddy, hag, pressed sugarcane, and dried plants are lower among solar adopters. Further, the expense of clean fuels such as gas or LPG is about 2%–16% more among the SHS households, depending on the survey round under consideration.

The effect of solar electrification on educational outcome

Solar adoption directly provides better illumination by replacing traditional lighting systems, resulting in an increase in household activity hours as well as children's desire for study and study time. According to Table 12, solar adoption boosted boys' years of schooling by roughly 0.60 years in both OLS and PSM estimations, but 0.42 years for girls in PSM results. According to our pooled PSM regressions, educational expenditure per boy student increased more than 20% in SHS homes, compared to 27% of OLS results. In the case of females, the cost fluctuated between 19% and 60% according to OLS estimates, but PSM did not provide any meaningful influence except the pooled PSM (21%). Surprisingly, girls' secondary enrolment rate decreased among SHS homes compared to non-SHS, although boys' secondary enrolment showed a positive influence among SHS families.

The effect of solar electrification on nutritional outcome

Although solar adaptation may not have a direct link with nutrition, it is connected indirectly through reduction in health hazard from dirty fuel use. According to both the OLS and PSM estimates, we found evidence of a reduction in all mentioned forms of stunting because of the adoption of solar in the three rounds of pooled data in Table 13. However, we have found no significant effect of solar adoption on children underweight in a pooled PSM analysis except for some improvements such as a decrease in moderate and severely underweight in OLS.

Discussion

Solar adoption

Solar is one of the alternative electrification solutions for households in hard-to-reach areas (Abu Saim & Khan, 2021). Government and non-government organizations also extend their institutional support to underprivileged areas. However, government's mass electrification program to electrify every house within 2021 might be the most plausible reasoning for the decrease in growth of SHS adoption in Bangladesh. In our findings, the negative coefficient of community electrification status and proportion of electrified households is the logical proof of this.

In general, people shift from solar to grid electricity due to the difference in cost of operation, quality of service (i.e., illumination) and the maintenance hassle (i.e., changing battery, panel, or other devices). For instances, the upfront cost of adoption of solar is much higher compared to electricity (Abu Saim & Khan, 2021; Khandker *et al*., 2014b). Other than that, solar is still subsidized by government and donor organizations (Biswas *et al.*, 2014). If they withdraw this support, it might not be economically feasible for poor households to operate (Khandker *et al*., 2014b).

Our results show that wealthy groups are using solar compared to the poorest group. Other variables related to the economic condition of a household like total land ownership and remittance also have a positive relationship with solar adoption which provides explanation for inaccessibility by the poor. These findings are in line with previous literature that focused on how economic conditions or wealth structure determines solar adoption (Aarakit *et al*., 2021; Best, 2023; Zander, 2020). However, some environmental, financial, and personal motivation also important determinant of solar uptake (Jacksohn *et al*., 2019; Schulte *et al*., 2022).

Economic gain and employment transition through solar adoption

Solar electrification increases illumination quality compared to traditional lighting methods such as candles and kerosene lamps. It may increase the productivity and encourage households to work longer hours or engage in trading or other income-generating business, which can increase household income (Jacobson, 2007; Mishra & Behera, 2016). In addition, solar energy can boost household income by giving members of the household access to news and information via electronic media like television and radio (Kabir *et al.*, 2017). With higher income, households like to live a better life and, therefore, the household food and non-food expenditure also might rise (Khandker *et al*., 2014b; Sharif & Mithila, 2013). This study also gives similar results, such as solar adoption has increased the total income, expenditure, food, and non-food expenditure, asset, and livestock value. However, some literature named solar as ornamentation and found no economic impact of it (Rahman & Ahmad, 2013).

Furthermore, solar adoption might change employment transition in the short run, especially in self-employment (Buragohain, 2012). Solar might influence households starting a business activity, and if they find these activities profitable, then they might gradually leave agricultural activity and engage in electricity-dependent businesses such as opening a grocery or other shops, poultry, and livestock farming. Our study has also found that solar shifts individuals from agriculture and involved males in trading and females in poultry business. This finding also suggests that solar empowers women to engage in more economic and negotiation opportunities in society, which supports Stock (2021) findings of how solar brings gender positive development. In the long run, they might permanently leave agricultural activity and get involved in solar-based profit-making businesses.

Environmental benefits through solar adoption

People in developing countries who do not have access to electricity primarily use kerosene-based lighting fuel and dirty cooking fuel. Both fuels produce a significant amount of CO_2 and are responsible for different health hazards. However, solar adoption replaces the environmentally harmful kerosene (Buragohain, 2012; Khandker *et al*., 2014b; Samad *et al*., 2013) and dirty fuel use with better quality lighting from solar and clean fuels such as gas. Although the kerosene replacement might have a strong explanation, clean fuel use might not be clear enough. One possible reason could be the household's fear of accidents in darker settings and kerosene lamps can even be dangerous if any leakage from a gas line or LPG cylinder.

Khandker *et al*. (2014b) found that solar adoption reduced monthly kerosene consumption by 2 litres. Cabraal *et al.* (2021) and Buragohain (2012) also found similar results. However, our dataset did not provide the amount of kerosene consumption in litres but the amount of expense on kerosene. Nevertheless, we provide a similar indication that kerosene consumption was reduced among solar households. In addition, we have also found that solar adoption reduces the expense of dirty fuels.

In addition, because dirty fuel produces enormous indoor smoke and putting fire on and off in a traditional dirty fuel stove is risky, in general, rural Bangladeshi households use a separate kitchen detached from the main house for cooking. When the SHS provides indoor light, it encourages households to use gas or LPG for cooking inside the main house. Our study also indicates that solar uptake increases the expense of gas or LPG by motivating people to use more clean energy.

Education and nutritional benefit through solar adoption

Children in developing countries cannot spent their time in study at night due to proper lighting and go to bed early (Mishra & Behera, 2016). This might hinder achieving their educational aspirations and cause them to fall behind in life. As a result, parents might think that their children have no potential for educational gain and withdraw from school. According to Khandker *et al.* (2014b), solar adoption had increased the children's years of schooling and school enrolment in Bangladesh, which, to some extent, is similar to our study. Solar can increase their study time and make them perform better in school (Wagner *et al*., 2021). Therefore, parents might find confidence in their children, invest in them, and keep in school for longer time. Our study also found that solar uptake increased parents' investment in children's education for both males and females. This might encourage children not to drop out from college and tertiary level education and form an educated labor force.

The use of solar instead of kerosene for illumination minimizes home air pollution (Obeng *et al*., 2008), which poses significant health risks to children (especially, the under-five child) and women who stay most of their time indoors. Kerosene substitution also cuts CO_2 emissions and decreases disease burden, particularly respiratory and gastrointestinal issues (Samad *et al*., 2013). In addition, solar electrification helps household members to watch television and engage in social media through mobile phones, which brings information about health-related awareness news and hygiene practices. Such information might help mothers to raise children properly and keep them healthy. This study did not find strong relationship between solar adoption and health outcomes, however, it has found that solar adoption decreases the stunting (mild, moderate, and severe) of under-five children.

Conclusions

Our study provides strong evidence of economic growth and environmental outcome, moderate occupational and educational outcomes, and some nutritional outcomes among SHS households. The enormous reduction in kerosene expenditure shows how solar plays an essential role in unelectrified areas. Rural males are more engaged in non-farm activities, such as trading businesses, and females are doing poultry farming due to solar adoption. These income-generating activities create opportunities for more expenses in food and non-food expenditure and asset formation, which is directly concerned with the nutrition (especially for under-five children). This study reveals that SHS households are investing more in their child's education and improving the nutritional status of under-five children. Therefore, the benefit of solar adoption might not be restricted to within generation; there might also be intergenerational effects on for instance health and education.

Despite the massive electrification projects of the Government of Bangladesh to electrify every house, the SHS remains relevant in hard-to-reach areas where electrification is not a viable alternative. In addition, even if people have electricity in their homes, they suffer regular load-shedding, particularly in rural areas. Solar might be a hybrid solution (that is, using solar with a grid connection as the solution for load-shedding) to deal with frequent power cuts in Bangladesh. The Government of Bangladesh is also taking initiatives to electrify government offices and union centres with rooftop solar systems.

Moreover, as a large part of the labour force in Bangladesh is employed in the agriculture sector, there might be enough potential for solar irrigation pumps and other solar-based agrotechnology. Moreover, as most of the surface of Bangladesh is flat, it gets enough direct sunlight to use large solar projects in the wasteland or floating solar projects in the sea and join those with the grid. Furthermore, recent global shocks have created uncertainty in the energy market. In such situation, solar might be thought as shock resilient electricity solution. As a result, we may conclude that to achieve universal electrification, the Government of Bangladesh should focus on the SDG aim of generating at least 10% of electricity from solar energy.

Our study has some limitations. Firstly, as we pooled three waves of data and applied the OLS and PSM techniques, it is impossible to control unobservable variables. Therefore, it is not possible to deny endogeneity and claim causal inference. Second, the findings apply to households who live in rural areas and do not use electricity as their main source of lighting. So, we cannot generalize the result for the whole Bangladeshi population.

Future study can focus on whether governments of developing countries can use solar electrification to protect their economics from energy crisis or uncertainty.

References

Aarakit, S. M., Ntayi, J. M., Wasswa, F., Adaramola, M. S., & Ssennono, V. F. (2021). Adoption of solar photovoltaic systems in households: Evidence from Uganda. *Journal of Cleaner Production*, *329*, 129619. doi: 10.1016/j.jclepro.2021.129619.

Abu Saim, Md., & Khan, I. (2021). Problematizing solar energy in Bangladesh: Benefits, burdens, and electricity access through solar home systems in remote islands. *Energy Research & Social Science*, *74*. doi: 10.1016/j.erss.2021.101969.

Ahmed, A. (2013). *Bangladesh Integrated Household Survey (BIHS) 2011–2012*. Washington: International Food Policy Research Institute. doi: 10.7910/DVN/OR6 MHT.

Bangladesh Planning Commission (2022). *Sustainable development goals: Bangladesh Progress report 2022*. Dhaka, Bangladesh. Retrieved from https://gedkp.gov.bd/wp-content/uploads/2023/02/SDGs-Progress-Report-2022-Final-output-file-1-February-2023-Full-book_compressed.pdf?post_id=3032#:~:text=As%20per%20the%20SDG%20index,our%20commitments%20to%20attaining%20SDGs.

Best, R. (2023). Assets power solar and battery uptake in Kenya. *Energy Economics*, *123*, 106723. doi: 10.1016/j.eneco.2023.106723.

Best, R., & Chareunsy, A. (2022). The impact of income on household solar panel uptake: Exploring diverse results using Australian data. *Energy Economics*, *112*, 106124. doi: 10.1016/j.eneco.2022.106124.

Best, R., Nepal, R., & Saba, N. (2021). Wealth effects on household solar uptake: Quantifying multiple channels. *Journal of Cleaner Production*, *297*, 126618. doi: 10.1016/j.jclepro.2021.126618.

Biswas, A. K., Sajjakulnukit, B., & Rakkwamsuk, P. (2014). Subsidy policy instruments for rapid growth of photovoltaic electricity generation in Bangladesh. *Energy Procedia*, *52*. doi: 10.1016/j.egypro.2014.07.055.

Buragohain, T. (2012). Impact of solar energy in rural development in India. *International Journal of Environmental Science and Development*, *3*(4), 334–338.

Cabraal, A., Ward, W. A., Bogach, V. S., & Jain, A. (2021). *Living in the light: The Bangladesh solar home systems story*. Washington: World Bank.

Crago, C. L., Grazier, E., & Breger, D. (2023). Income and racial disparities in financial returns from solar PV deployment. *Energy Economics*, *117*, 106409. doi: 10.1016/j.eneco.2022.106409.

Hancevic, P. I., & Sandoval, H. H. (2023). Solar panel adoption among Mexican small and medium-sized commercial and service businesses. *Energy Economics*, *126*, 106979. doi: 10.1016/j.eneco.2023.106979.

IFPRI (2016). *Bangladesh integrated household survey (BIHS) 2015*. Washington: International Food Policy Research Institute.

IFPRI (2020). *Bangladesh integrated household survey (BIHS) 2018-2019*. Washington: International Food Policy Research Institute. doi: 10.7910/DVN/NXKLZJ.

Jacksohn, A., Grösche, P., Rehdanz, K., & Schröder, C. (2019). Drivers of renewable technology adoption in the household sector. *Energy Economics*, *81*, 216–226. doi: 10.1016/j.eneco.2019.04.001.

Jacobson, A. (2007). Connective power: Solar electrification and social change in Kenya. *World Development*, *35*(1), 144–162. doi: 10.1016/j.worlddev.2006.10.001.

Kabir, E., Kim, K.-H., & Szulejko, J. (2017). Social impacts of solar home systems in rural areas: A case study in Bangladesh. *Energies*, *10*(10), 1615. doi: 10.3390/en10101615.

Khan, I. (2019). Drivers, enablers, and barriers to prosumerism in Bangladesh: A sustainable solution to energy poverty? *Energy Research & Social Science*, *55*, 82–92. doi: 10.1016/j.erss.2019.04.019.

Khandker, S. R., Samad, H. A., Ali, R., & Barnes, D. F. (2014a). Who benefits most from rural electrification? Evidence in India. *Energy Journal*, *35*(2), 75–96. doi: 10.5547/01956574.35.2.4.

Khandker, S. R., Samad, H. A., Sadeque, Z. K. M., Asaduzzaman, M., Yunus, M., & Haque, A. K. E. (2014b). *Surge in solar-powered homes: Experience in off-grid rural Bangladesh*. The World Bank. doi: 10.1596/978-1-4648-0374-1.

Komatsu, S., Kaneko, S., Ghosh, P. P., & Morinaga, A. (2013). Determinants of user satisfaction with solar home systems in rural Bangladesh. *Energy*, *61*, 52–58. doi: 10.1016/j.energy.2013.04.022.

Komatsu, S., Kaneko, S., Shrestha, R. M., & Ghosh, P. P. (2011). Nonincome factors behind the purchase decisions of solar home systems in rural Bangladesh. *Energy for Sustainable Development*, *15*(3), 284–292. doi: 10.1016/j.esd.2011.03.003.

Liao, C., Fei, D., Huang, Q., Jiang, L., & Shi, P. (2021). Targeted poverty alleviation through photovoltaic-based intervention: Rhetoric and reality in Qinghai, China. *World Development*, *137*, 105117. doi: 10.1016/j.worlddev.2020.105117.

Mishra, P., & Behera, B. (2016). Socio-economic and environmental implications of solar electrification: Experience of rural Odisha. *Renewable and Sustainable Energy Reviews*, *56*, 953–964. doi: 10.1016/j.rser.2015.11.075.

Obeng, G. Y., Akuffo, F. O., Braimah, I., Evers, H.-D., & Mensah, E. (2008). Impact of solar photovoltaic lighting on indoor air smoke in off-grid rural Ghana. *Energy for Sustainable Development*, *12*(1), 55–61. doi: 10.1016/S0973-0826(08)60419-6.

Pueyo, A., & DeMartino, S. (2018). The impact of solar mini-grids on Kenya's rural enterprises. *Energy for Sustainable Development*, *45*, 28–37. doi: 10.1016/j.esd.2018.04.002.

Rahman, S. M., & Ahmad, M. M. (2013). Solar home system (SHS) in rural Bangladesh: Ornamentation or fact of development? *Energy Policy*, *63*, 348–354. doi: 10.1016/j.enpol.2013.08.041.
Samad, H. A., Khandker, S. R., Asaduzzaman, M., & Yunusd, M. (2013). The benefits of solar home systems: An analysis from Bangladesh. *World Bank Policy Research Working Paper*, *6724*. doi: 10.1596/1813-9450-6724.
Schulte, E., Scheller, F., Sloot, D., & Bruckner, T. (2022). A meta-analysis of residential PV adoption: The important role of perceived benefits, intentions and antecedents in solar energy acceptance. *Energy Research & Social Science*, *84*, 102339. doi: 10.1016/j.erss.2021.102339.
Sharif, I., & Mithila, M. (2013). Rural electrification using PV: The success story of Bangladesh. *Energy Procedia*, *33*, 343–354. doi: 10.1016/j.egypro.2013.05.075.
Stock, R. (2021). Bright as night: Illuminating the antinomies of 'gender positive' solar development. *World Development*, *138*, 105196. doi: 10.1016/j.worlddev.2020.105196.
Urpelainen, J. (2016). Energy poverty and perceptions of solar power in marginalized communities: Survey evidence from Uttar Pradesh, India. *Renewable Energy*, *85*, 534–539. doi: 10.1016/j.renene.2015.07.001.
Wagner, N., Rieger, M., Bedi, A. S., Vermeulen, J., & Demena, B. A. (2021). The impact of off-grid solar home systems in Kenya on energy consumption and expenditures. *Energy Economics*, *99*, 105314. doi: 10.1016/j.eneco.2021.105314.
Wijayatunga, P. D. C., & Attalage, R. A. (2005). Socio-economic impact of solar home systems in rural Sri Lanka: A case-study. *Energy for Sustainable Development*, *9*(2), 5–9. doi: 10.1016/S0973-0826(08)60487-1.
Zander, K. K. (2020). Unrealised opportunities for residential solar panels in Australia. *Energy Policy*, *142*, 111508. doi: 10.1016/j.enpol.2020.111508.

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Annex

Table 1. Definitions of control variables

Variables	Definitions
Sex of Head	1 if the head of household is male
Age and age squared	Age of head of household in years
Education of head of the household	Number of grades completed by the head of household and his spouse
Household size	Number of family members in the household
Log of the total land	Log of total land holdings by household
Remittance	1 if the household has someone abroad or receives remittance from abroad
Loan	1 if access to any loan
Electricity poverty	1 if electricity is poor (an index developed based on the use of electric equipment)
Shock	1 if the household faces any shocks such as economic, health, or environmental
Year	2011–2012 (reference) = 0, 2015 = 1 and 2018–2019 = 2
Wealth index	It is calculated using a principal component analysis of assets owned by households (such as cabinet, table/chair, fan, watch, tv, bicycle, tube well and sanitary latrine) at the time of the interview. The score was then divided into five equal quintiles with the first one representing the poorest 20% and the fifth one representing the richest 20%.
Community electrification status	1 if the village where the household lives are electrified
% of electrified household	Percentage of electrified households in that village
Bazar within community	1 if the existence of a bazar within the community
Concrete road within the community	1 if the existence of a concrete road within the community
Motor-based public transport to go to town	1 if the existence of motor-based public transport to go to town
Divisional dummy	7 administrative divisions

Table 2. Summary statistics of the variables

Variables	N	Mean	Std. Dev.	Min	Max
Sex of Head	6712	0.819279	0.384816	0	1
Age	6712	44.97765	14.14981	17	93
Age Squared	6712	2223.176	1394.998	289	8649
Education of head of the household	6712	2.478993	3.439388	0	22
Household size	6712	4.158224	1.648973	1	17
Log of the total land	6712	3.469384	1.559071	0	8.0368
Remittance	6712	0.026371	0.160247	0	1
Loan	6712	0.671484	0.469709	0	1

Table 2. Continued

Variables	N	Mean	Std. Dev.	Min	Max
Shock	6712	0.497765	0.500032	0	1
Wealth index	6712	2.63826	1.402772	1	5
Year	6712	2013.465	2.725337	2011	2019
Community electrification status	6712	0.694875	0.460495	0	1
% of electrified household	6712	31.69918	30.20083	0	96.428
Bazar within community	6712	0.404201	0.490773	0	1
Concrete road within the community	6712	0.357569	0.47932	0	1
Motor-based public transport to go to town	6712	0.513707	0.499849	0	1

Table 3. Bivariate analysis of economic outcomes

	2011 Solar		P-value	2015 Solar		P-value	2019 Solar		P-value
	Yes	No		**Yes**	**No**		**Yes**	**No**	
Monthly total income per person	1,490.11	848.03	0.000	1,128.03	928.33	0.000	1,043.91	862.77	0.004
	(2,068.81)	(739.15)		(926.05)	(864.22)		(1,010.12)	(603.37)	
Monthly expenditure per person	1,929.76	1,210.24	0.000	1,639.95	1,420.32	0.000	1,321.07	1,155.47	0.007
	(1,364.43)	(838.25)		(994.82)	(976.92)		(912.15)	(749.30)	
Monthly food expenditure per person	977.51	797.48	0.000	823.07	747.32	0.000	768.79	794.62	0.561
	(568.81)	(434.27)		(479.85)	(421.67)		(606.91)	(610.07)	
Monthly non-food expenditure per person	320.34	143.61	0.000	197.68	168.42	0.000	135.07	110.52	0.000
	(636.75)	(326.11)		(161.83)	(124.33)		(92.40)	(71.44)	
Household asset value per person	11,135.91	2,550.96	0.000	8,334.73	3,896.04	0.000	7,726.81	3,568.28	0.000
	(21,237.02)	(4,953.38)		(9,049.90)	(4,686.57)		(7,504.87)	(4,132.96)	
Agri asset value per person	2,248.56	429.89	0.000	564.54	328.09	0.000	427.61	226.11	0.006
	(20,626.19)	(3,472.34)		(1,407.27)	(1,031.79)		(1,078.67)	(576.83)	
Harvest value per person	5,093.79	2,622.17	0.000	2,506.94	2,027.32	0.001	3,731.16	2,152.31	0.000
	(16,945.90)	(4,484.23)		(3,411.18)	(3,250.19)		(5,757.13)	(3,827.18)	

Table 4. Bivariate analysis of occupational outcomes

	2011			2015			2019		
	Solar		P-value	Solar		P-value	Solar		P-value
	Yes	No		Yes	No		Yes	No	
Male households									
Sharecropping	0.13	0.16	0.159	0.18	0.18	0.708	0.18	0.18	0.935
	(0.34)	(0.37)		(0.39)	(0.38)		(0.39)	(0.38)	
Poultry	0.02	0.01	0.064	0.01	0.01	0.087	0.02	0.03	0.422
	(0.13)	(0.08)		(0.09)	(0.12)		(0.15)	(0.18)	
Trading	0.16	0.12	0.037	0.16	0.12	0.003	0.12	0.09	0.173
	(0.37)	(0.32)		(0.36)	(0.32)		(0.33)	(0.29)	
Female households									
Sharecropping	0.01	0.01	0.999	0.02	0.01	0.502	0.03	0.02	0.765
	(0.10)	(0.10)		(0.13)	(0.12)		(0.16)	(0.15)	
Poultry	0.79	0.69	0.002	0.79	0.73	0.003	0.81	0.65	0.000
	(0.41)	(0.46)		(0.41)	(0.44)		(0.39)	(0.48)	
Trading	0.01	0.02	0.323	0.02	0.02	0.601	0.02	0.01	0.475
	(0.10)	(0.13)		(0.14)	(0.13)		(0.13)	(0.11)	

Table 5. Bivariate analysis of environmental outcomes

	2011 Solar		P-value	2015 Solar		P-value	2019 Solar		P-value
	Yes	**No**		**Yes**	**No**		**Yes**	**No**	
Monthly kerosene expense per person	7.44	18.26	0.000	2.27	15.65	0.000	0.77	12.47	0.000
	(27.08)	(13.37)		(5.85)	(10.04)		(2.11)	(8.37)	
Monthly agri fuel (paddy) expense per person	22.24	32.35	0.000	24.50	31.13	0.000	17.08	26.68	0.000
	(33.82)	(39.45)		(24.86)	(30.39)		(16.83)	(27.12)	
Monthly liquefied petroleum gas expense per person	2.01	0.09	0.000	0.36	0.11	0.097	4.33	0.72	0.000
	(17.31)	(2.47)		(5.60)	(1.95)		(17.44)	(5.42)	

Table 6. Bivariate analysis of educational outcomes

	2011			2015			2019		
	Solar		P-value	Solar		P-value	Solar		P-value
	Yes	**No**		**Yes**	**No**		Yes	**No**	
Male students									
Years of education	4.84	3.26	0.000	4.86	3.92	0.000	4.36	3.40	0.002
	(3.49)	(2.92)		(3.47)	(2.97)		(3.45)	(2.82)	
Enrolment in secondary school	0.38	0.20	0.000	0.38	0.27	0.000	0.31	0.20	0.010
	(0.49)	(0.40)		(0.49)	(0.45)		(0.46)	(0.40)	
Education expenditure per male student	3,612.49	1,828.02	0.000	2,836.26	2,068.25	0.000	3,398.91	2,727.25	0.116
	(3,762.56)	(2,300.86)		(3,635.63)	(3,024.88)		(5,014.96)	(3,280.90)	
Female students									
Years of education	5.17	3.44	0.000	4.73	4.29	0.002	4.71	4.24	0.118
	(3.40)	(2.88)		(3.14)	(3.02)		(3.24)	(3.06)	
Enrolment in secondary school	0.40	0.23	0.000	0.37	0.33	0.049	0.38	0.28	0.028
	(0.49)	(0.42)		(0.48)	(0.47)		(0.49)	(0.45)	
Education expenditure per male student	3,313.81	1,646.51	0.000	2,194.01	1,690.69	0.000	3,313.11	2,183.43	0.009
	(3,451.06)	(1,979.27)		(3,183.49)	(2,162.72)		(5,323.73)	(2,625.63)	

Table 7. Bivariate analysis of nutritional outcomes

	2011			**2015**			**2019**		
	Solar		**P-value**	**Solar**		**P-value**	**Solar**		**P-value**
	Yes	**No**		Yes	**No**		**Yes**	**No**	
Low stunting	0.65	0.78	0.005	0.71	0.75	0.159	0.69	0.78	0.084
	(0.48)	(0.41)		(0.45)	(0.43)		(0.46)	(0.41)	
Moderate stunting	0.41	0.51	0.069	0.35	0.46	0.002	0.36	0.44	0.157
	(0.50)	(0.50)		(0.48)	(0.50)		(0.48)	(0.50)	
High stunting	0.16	0.22	0.242	0.12	0.16	0.135	0.11	0.17	0.114
	(0.37)	(0.41)		(0.33)	(0.37)		(0.31)	(0.38)	
Low underweight	0.67	0.74	0.148	0.71	0.76	0.063	0.64	0.69	0.358
	(0.47)	(0.44)		(0.45)	(0.42)		(0.48)	(0.47)	
Moderate underweight	0.28	0.39	0.053	0.35	0.38	0.379	0.24	0.35	0.040
	(0.45)	(0.49)		(0.48)	(0.49)		(0.43)	(0.48)	
High underweight	0.07	0.12	0.171	0.09	0.11	0.325	0.07	0.10	0.254
	(0.26)	(0.33)		(0.28)	(0.31)		(0.25)	(0.31)	

Table 8. The determinants of solar adoption

Variables	(1) OLS	(2) Probit (Marginal Effect)
Male head	-0.043***	-0.042***
	(0.013)	(0.013)
Age of head	-0.001	-0.001
	(0.002)	(0.002)
Age square of head	0.000	0.000
	(0.000)	(0.000)
Head education in years	0.011***	0.009***
	(0.002)	(0.001)
Total households	0.017***	0.012***
	(0.003)	(0.003)
Log of the total land	0.035***	0.036***
	(0.004)	(0.004)
Remittance household	0.062**	0.067***
	(0.029)	(0.023)
Loan taken	0.016*	0.012
	(0.009)	(0.010)
At least 1 shock in the last 3 years	0.015	0.014
	(0.009)	(0.009)
Wealth index = 2, poor	0.053***	0.035***
	(0.011)	(0.010)
Wealth index = 3, middle	0.084***	0.072***
	(0.015)	(0.014)
Wealth index = 4, rich	0.096***	0.093***
	(0.018)	(0.017)
Wealth index = 5, richest	0.068***	0.071***
	(0.021)	(0.019)
Division = Chittagong	0.005	0.029
	(0.029)	(0.028)
Division =Dhaka	-0.010	0.001
	(0.026)	(0.024)
Division = Khulna	-0.040	-0.035
	(0.034)	(0.033)
Division = Rajshahi	-0.091***	-0.091***
	(0.031)	(0.029)
Division = Rangpur	-0.129***	-0.108***
	(0.028)	(0.026)
Division = Sylhet	0.033	0.043*
	(0.029)	(0.025)
Year = 2015	0.240***	0.237***
	(0.015)	(0.013)
Year = 2019	0.525***	0.543***
	(0.023)	(0.021)
Community electrification status	-0.117***	-0.078***
	(0.026)	(0.020)
% of electrified household	-0.003***	-0.002***
	(0.000)	(0.000)
Bazar within community	-0.016	-0.014
	(0.015)	(0.014)
Concrete road within the community	-0.023	-0.044***
	(0.016)	(0.014)

Table 8. Continued

Variables	(1) OLS	(2) Probit (Marginal Effect)
Motor-based public transport to go to town	-0.005	-0.008
	(0.014)	(0.011)
Constant	0.051	
	(0.052)	-
Observations	6,712	6,712

Note: *** p<0.01, ** p<0.05, * p<0.1; Robust standard errors in parentheses.

Table 9. The effect of solar electrification on economic outcome

Methods	(1) Log of Total Income	(2) Log of Total Expense	(3) Log of Food Expense	(4) Log of Non-food Expense	(5) Log of HH Asset Value	(6) Log of Agri Asset Value	(7) Log of Animal Value
Year: 2011–2012							
OLS	0.235**	0.282***	0.221***	0.336***	1.085***	0.330*	0.080
	(0.092)	(0.045)	(0.043)	(0.067)	(0.081)	(0.171)	(0.153)
PSM (nearest neighbour)	0.222*	0.264***	0.140***	0.439***	1.243***	-0.067	-0.006
	(0.122)	(0.073)	(0.052)	(0.064)	(0.113)	(0.169)	(0.182)
Year: 2015							
OLS	0.212***	0.129***	0.160***	0.105***	0.692***	0.241**	0.057
	(0.044)	(0.033)	(0.037)	(0.040)	(0.049)	(0.097)	(0.127)
PSM (nearest neighbour)	0.185***	0.133***	0.155***	0.156***	0.739***	0.152	0.145
	(0.053)	(0.031)	(0.031)	(0.038)	(0.045)	(0.094)	(0.125)
Year: 2018–2019							
OLS	0.073	0.116**	0.081*	0.070	0.618***	0.043	0.645***
	(0.094)	(0.046)	(0.048)	(0.060)	(0.089)	(0.123)	(0.221)
PSM (nearest neighbour)	0.067	0.127***	0.038	0.120**	0.677***	0.128	0.908***
	(0.089)	(0.047)	(0.048)	(0.055)	(0.077)	(0.124)	(0.263)
Pooled Data (2011–2012 and 2015)							
OLS	0.250***	0.171***	0.169***	0.154***	0.821***	0.271***	0.163
	(0.042)	(0.028)	(0.031)	(0.040)	(0.048)	(0.098)	(0.103)
PSM (nearest neighbour)	0.229***	0.257***	0.152***	0.352***	1.042***	0.401***	-0.32***
	(0.044)	(0.027)	(0.025)	(0.042)	(0.046)	(0.081)	(0.110)

Table 9. Continued

Methods	(1) Log of Total Income	(2) Log of Total Expense	(3) Log of Food Expense	(4) Log of Non-food Expense	(5) Log of HH Asset Value	(6) Log of Agri Asset Value	(7) Log of Animal Value
Pooled Data (2011–2012, 2015, and 2018–2019)							
OLS	0.216***	0.159***	0.148***	0.139***	0.785***	0.237***	0.270**
	(0.040)	(0.025)	(0.027)	(0.036)	(0.044)	(0.087)	(0.105)
PSM (nearest neighbour)	0.193***	0.149***	0.085***	0.179***	1.024***	0.399***	-0.142
	(0.040)	(0.022)	(0.022)	(0.029)	(0.035)	(0.069)	(0.099)

Notes: *** p<0.01, ** p<0.05, * p<0.1, HH = household, OLS = ordinary least square, PSM = propensity score matching.

1. Robust standard errors in parentheses for OLS estimate.
2. The following control variables are included in the PSM estimation equation: sex of head, age of head, head's education, household size, log of total land, loan, shock and wealth index
3. The following control variables are included in the OLS estimation equation: sex of head, age of head, age squared, head's education, household size, log of total land, presence of remittance holder in house, loan, wealth index, administrative division, survey year, community electrification status, % of electrified household, bazar and concrete road within the community, and motor-based public transport to go to the town.

Table 10. The effect of solar electrification on employment outcome

Methods	(1) Male: Sharecropping	(2) Male: Poultry Farming	(3) Male: Trading Business	(4) Female: Sharecropping	(5) Female: Poultry Farming	(6) Female: Trading Business
Year: 2011–2012						
OLS	-0.090***	0.009	0.045	-0.090***	0.029	-0.003
	(0.024)	(0.009)	(0.028)	(0.024)	(0.033)	(0.008)
PSM (nearest neighbour)	-0.032	-0.001	0.077	-0.006**	0.095	0.028
	(0.026)	(0.005)	(0.049)	(0.003)	(0.059)	(0.050)
Year: 2015						
OLS	-0.006	-0.013**	0.050***	-0.006	0.039	0.006
	(0.020)	(0.005)	(0.019)	(0.020)	(0.025)	(0.007)
PSM (nearest neighbour)	-0.031**	-0.011**	0.053***	-0.001	0.029	0.011
	(0.015)	(0.004)	(0.016)	(0.005)	(0.019)	(0.007)
Year: 2018–2019						
OLS	-0.028	-0.014	0.052*	-0.028	0.053	0.014
	(0.034)	(0.017)	(0.031)	(0.034)	(0.043)	(0.009)
PSM (nearest neighbour)	-0.058	0.000	0.066***	-0.012	0.088***	0.011*
	(0.043)	(0.011)	(0.021)	(0.017)	(0.032)	(0.006)
Pooled Data (2011–2012 and 2015)						
OLS	-0.032**	-0.006	0.046***	-0.032**	0.020	0.004
	(0.016)	(0.004)	(0.016)	(0.016)	(0.020)	(0.006)
PSM (nearest neighbour)	-0.033***	-0.005**	0.049***	0.001	0.072***	0.008
	(0.012)	(0.002)	(0.015)	(0.004)	(0.018)	(0.007)

Table 10. Continued

Methods	(1) Male: Sharecropping	(2) Male: Poultry Farming	(3) Male: Trading Business	(4) Female: Sharecropping	(5) Female: Poultry Farming	(6) Female: Trading Business
Pooled Data (2011–2012, 2015, and 2018–2019)						
OLS	-0.031**	-0.007	0.046***	-0.031**	0.033*	0.006
	(0.014)	(0.005)	(0.015)	(0.014)	(0.019)	(0.005)
PSM (nearest	-0.037***	0.001	0.026**	0.006	0.076***	0.008
neighbour)	(0.010)	(0.004)	(0.011)	(0.004)	(0.015)	(0.005)

Notes: *** p<0.01, ** p<0.05, * p<0.1, OLS = ordinary least square, PSM = propensity score matching.

1. Robust standard errors in parentheses for OLS estimate.
2. The following control variables are included in the PSM estimation equation: sex of head, age of head, head's education, household size, log of total land, loan, shock, and wealth index
3. The following control variables are included in the OLS estimation equation: sex of head, age of head, age squared, head's education, household size, log of total land, presence of remittance holder in house, loan, wealth index, administrative division, survey year, community electrification status, % of electrified household, bazar and concrete road within the community, and motor-based public transport to go to the town.

Table 11. The effect of solar electrification on environmental outcome

Methods	(1) Log of Kerosene Expense	(2) Log of Agri-fuel Expense	(3) Log of Gas/LPG Expense
Year: 2011–2012			
OLS	-1.648***	-0.660***	0.083**
	(0.091)	(0.121)	(0.041)
PSM (nearest neighbour)	-1.563***	-0.566***	0.039
	(0.127)	(0.207)	(0.028)
Year: 2015			
OLS	-2.116***	0.076	0.023*
	(0.056)	(0.083)	(0.014)
PSM (nearest neighbour)	-2.078***	-0.023	0.010
	(0.045)	(0.077)	(0.008)
Year: 2018–2019			
OLS	-2.205***	-0.018	0.165**
	(0.055)	(0.107)	(0.070)
PSM (nearest neighbour)	-2.126***	-0.095	0.153**
	(0.050)	(0.117)	(0.062)
Pooled Data (2011–2012 and 2015)			
OLS	-1.998***	-0.194***	0.040***
	(0.049)	(0.072)	(0.015)
PSM (nearest neighbour)	-1.999***	-0.079	0.022**
	(0.048)	(0.076)	(0.010)

Table 11. Continued

Methods	(1) Log of Kerosene Expense	(2) Log of Agri-fuel Expense	(3) Log of Gas/LPG Expense
Pooled Data (2011–2012, 2015, and 2018–2019)			
OLS	-2.035***	-0.183***	0.075***
	(0.041)	(0.062)	(0.020)
PSM (nearest neighbour)	-2.156***	-0.046	0.104***
	(0.033)	(0.056)	(0.019)

Notes: *** p<0.01, ** p<0.05, * p<0.1, LPG = liquefied petroleum gas, OLS = ordinary least square, PSM = propensity score matching.
1. Robust standard errors in parentheses for OLS estimate.
2. The following control variables are included in the PSM estimation equation: sex of head, age of head, head's education, household size, log of total land, loan, shock, and wealth index
3. The following control variables are included in the OLS estimation equation: sex of head, age of head, age squared, head's education, household size, log of total land, presence of remittance holder in house, loan, wealth index, administrative division, survey year, community electrification status, % of electrified household, bazar and concrete road within the community, and motor-based public transport to go to the town.

Table 12. The Effect of Solar Electrification on Educational Outcome

Methods	(1) **Boys: Years of Education**	(2) **Girls: Years of Education**	(3) **Boys: School Enrolment**	(4) **Girls: School Enrolment**	(5) **Boys: Education Expense per Student**	(6) **Girls: Education Expense per Student**
Year: 2011–2012						
OLS	0.820***	0.733***	0.038	-0.019	0.301*	0.419**
	(0.270)	(0.257)	(0.047)	(0.049)	(0.174)	(0.174)
PSM (nearest neighbour)	0.400*	0.214	0.015	-0.087**	0.851***	0.093
	(0.240)	(0.319)	(0.051)	(0.035)	(0.130)	(0.278)
Year: 2015						
OLS	0.510***	0.178	0.063	-0.015	0.386***	0.098
	(0.185)	(0.174)	(0.039)	(0.035)	(0.097)	(0.125)
PSM (nearest neighbour)	0.434**	-0.193	0.083**	-0.034	0.097	0.004
	(0.187)	(0.170)	(0.033)	(0.037)	(0.136)	(0.121)
Year: 2018–2019						
OLS	0.435	0.622*	0.127*	0.061	-0.092	0.589**
	(0.299)	(0.342)	(0.075)	(0.069)	(0.241)	(0.225)
PSM (nearest neighbour)	0.330	0.238	0.061	0.033	-0.489***	0.432
	(0.339)	(0.317)	(0.064)	(0.062)	(0.179)	(0.300)

Table 12. Continued

Methods	(1) **Boys: Years of Education**	(2) **Girls: Years of Education**	(3) **Boys: School Enrolment**	(4) **Girls: School Enrolment**	(5) **Boys: Education Expense per Student**	(6) **Girls: Education Expense per Student**
Pooled Data (2011–2012 and 2015)						
OLS	0.628***	0.285*	0.055*	-0.023	0.327***	0.191*
	(0.163)	(0.156)	(0.032)	(0.029)	(0.083)	(0.106)
PSM (nearest neighbour)	0.872***	0.491***	0.127***	0.016	0.362***	0.076
	(0.136)	(0.136)	(0.030)	(0.028)	(0.098)	(0.103)
Pooled Data (2011–2012, 2015, and 2018–2019)						
OLS	0.582***	0.305**	0.055*	-0.009	0.278***	0.256***
	(0.149)	(0.140)	(0.030)	(0.026)	(0.084)	(0.095)
PSM (nearest neighbour)	0.647***	0.418***	0.072***	0.028	0.205**	0.214**
	(0.125)	(0.115)	(0.026)	(0.023)	(0.104)	(0.099)

Notes: *** p<0.01, ** p<0.05, * p<0.1, OLS = ordinary least square, PSM = propensity score matching.

1. Robust standard errors in parentheses for OLS estimate.
2. The following control variables are included in the PSM estimation equation: sex of head, age of head, head's education, household size, log of total land, loan, shock, and wealth index
3. The following control variables are included in the OLS estimation equation: sex of head, age of head, age squared, head's education, household size, log of total land, presence of remittance holder in house, loan, wealth index, administrative division, survey year, community electrification status, % of electrified household, bazar and concrete road within the community, and motor-based public transport to go to the town.

Table 13. The Effect of Solar Electrification on Nutritional Outcome (Under Five Children)

Methods	**(1)** **Mild stunting (haz<-1)**	**(2)** **Moderate stunting (haz<-2)**	**(3)** **Severe stunting (haz<-3)**	**(4)** **Mild Underweight (waz<-1)**	**(5)** **Moderate Underweight (waz<-2)**	**(6)** **Severe Underweight (waz<-3)**
Year: 2011–2012						
OLS	-0.115**	-0.093*	-0.050	-0.043	-0.079	-0.049
	(0.048)	(0.056)	(0.051)	(0.058)	(0.059)	(0.036)
PSM (nearest neighbour)	-0.131*	-0.020	0.090	-0.018	0.028	-0.000
	(0.079)	(0.090)	(0.075)	(0.063)	(0.062)	(0.113)
Year: 2015						
OLS	-0.010	-0.068	-0.032	-0.009	0.044	-0.001
	(0.039)	(0.044)	(0.033)	(0.040)	(0.046)	(0.026)
PSM (nearest neighbour)	-0.023	-0.069*	-0.057*	0.006	0.006	-0.021
	(0.035)	(0.041)	(0.031)	(0.032)	(0.041)	(0.032)

Table 13. Continued

Methods	(1) **Mild stunting (haz<-1)**	(2) **Moderate stunting (haz<-2)**	(3) **Severe stunting (haz<-3)**	(4) **Mild Underweight (waz<-1)**	(5) **Moderate Underweight (waz<-2)**	(6) **Severe Underweight (waz<-3)**
Year: 2018– 2019						
OLS	-0.044	-0.037	-0.085**	0.005	-0.099	-0.044
	(0.050)	(0.062)	(0.039)	(0.055)	(0.060)	(0.037)
PSM (nearest neighbour)	-0.049	-0.069	-0.108*	-0.006	-0.098	-0.060*
	(0.050)	(0.066)	(0.057)	(0.052)	(0.061)	(0.031)
Pooled Data (2011–2012 and 2015)						
OLS	-0.052**	-0.113***	-0.066***	-0.014	-0.012	-0.024
	(0.026)	(0.030)	(0.025)	(0.031)	(0.033)	(0.019)
PSM (nearest neighbour)	-0.057	-0.104***	-0.061**	0.002	0.003	-0.019
	(0.036)	(0.032)	(0.024)	(0.032)	(0.042)	(0.029)
Pooled Data (2011–2012, 2015, and 2018–2019)						
OLS	-0.049**	-0.101***	-0.072***	-0.034	-0.047*	-0.028*
	(0.021)	(0.026)	(0.020)	(0.026)	(0.027)	(0.015)
PSM (nearest neighbour)	-0.040*	-0.088**	-0.054**	-0.019	-0.049	-0.030
	(0.023)	(0.035)	(0.025)	(0.028)	(0.033)	(0.021)

Notes: *** p<0.01, ** p<0.05, * p<0.1, HH = household, OLS = ordinary least square, PSM = propensity score matching.

Notes:

1. Robust standard errors in parentheses for OLS estimate.
2. The following control variables are included in the PSM estimation equation: sex of head, age of head, head's education, household size, log of total land, loan, shock, and wealth index
3. The following control variables are included in the OLS estimation equation: sex of head, age of head, age squared, head's education, household size, log of total land, presence of remittance holder in house, loan, wealth index, administrative division, survey year, community electrification status, % of electrified household, bazar and concrete road within the community, and motor-based public transport to go to the town.

Appendix

As the employment categories are unordered categorical variable, we also applied the multinomial model for different years separately and together in Table A1. All other occupations except sharecropping, poultry and trading business are kept under 'Others' which is not mentioned here for comparability with the original result.

Table A1. The Effect of Solar Electrification on Employment Outcome (Multinomial Regression Model)t

	(1) Male: Sharecrop ping	(2) Male: Poultry Farming	(3) Male: Trading Business	(4) Female: Sharecrop ping	(5) Female: Poultry Farming	(6) Female: Trading Business
Year: 2011–2012						
Solar (only)	-0.031	0.007*	0.039**	-0.001	0.119***	-0.011
	(0.022)	(0.004)	(0.019)	(0.006)	(0.035)	(0.011)
Solar (with Control Variables)	-0.083***	0.003	0.037*	-0.002	0.049	-0.007
	(0.021)	(0.004)	(0.020)	(0.004)	(0.036)	(0.011)
Year: 2015						
Solar (only)	0.002	-0.008**	0.037***	-0.003	0.054***	0.003
	(0.014)	(0.004)	(0.013)	(0.003)	(0.018)	(0.005)
Solar (with Control Variables)	-0.035**	-0.007**	0.044***	-0.004	0.032*	0.008
	(0.014)	(0.003)	(0.014)	(0.003)	(0.019)	(0.005)
Year: 2018–2019						
Solar (only)	0.010	-0.008	0.032	-0.000	0.147***	0.006
	(0.027)	(0.011)	(0.023)	(0.007)	(0.029)	(0.009)
Solar (with Control Variables)	-0.049*	-0.004	0.039	-0.002	0.104***	0.009
	(0.026)	(0.010)	(0.026)	(0.005)	(0.032)	(0.008)
Pooled Data (2011–2012 and 2015)						
Solar (only)	-0.000	-0.001	0.037***	-0.002	0.089***	-0.000
	(0.011)	(0.003)	(0.010)	(0.003)	(0.015)	(0.004)
Solar (with Control Variables)	-0.041***	-0.003	0.038***	-0.003	0.058***	0.004
	(0.011)	(0.003)	(0.010)	(0.002)	(0.016)	(0.004)
Pooled Data (2011–2012, 2015, and 2018–2019)						
Solar (only)	0.004	0.002	0.030***	-0.001	0.099***	0.000
	(0.010)	(0.003)	(0.009)	(0.002)	(0.013)	(0.004)
Solar (with Control Variables)	-0.034***	-0.000	0.032***	-0.002	0.068***	0.004
	(0.009)	(0.002)	(0.009)	(0.002)	(0.014)	(0.004)

Notes: *** p<0.01, ** p<0.05, * p<0.1

1. The following control variables are included in the estimation equation: sex of head, age of head, head's education, household size, log of total land, loan, shock, and wealth index
2. All other occupations except sharecropping, poultry and trading business are kept under 'Others' which is not mentioned here.