SOCIAL BENEFITS OF CLEAN ENERGY

EVIDENCE FROM BANGLADESH

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ABSTRACT

Solar adoption exploded until 2015 in Bangladesh, setting a precedent for electrifying previously unconnected areas worldwide. This study tries to measure the welfare effects of solar adoption using the three rounds of the Bangladesh Integrated Household Surveys. We applied both ordinary least squares and propensity score matching techniques to estimate the welfare effects of solar adoption. We found that solar adoption is associated with higher income, expenditure, and asset value growth, and a massive reduction in kerosene expenditure than non-adopters. Other findings include that solar households tend to abandon sharecropping in favor of trading and poultry farming, and that children in solar households benefit in terms of schooling and nutrition.

Keywords: energy transition, solar adoption, education, welfare, Bangladesh

JEL codes: O13, Q42, D12, O55

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I. 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, Samad, Sadeque et al. 2014). 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. Therefore, solar can be thought of as an urban solution as well in regions of frequent power outages.

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-going children. In addition, people get recreational and educative information and knowledge from television, radio, and cellphone 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 (Buragohain 2012; Sharif and Mithila 2013). SHSs have raised household living standards, particularly for women, and increased children's study time (Komatsu et al. 2013; Mishra and 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 and Behera 2016).

Despite a significant number of literatures that focused on on-grid electrification's implications, few studies have analyzed the effect of solar adoption on the livelihood and welfare of rural Bangladeshi people. Khandker et al. 2014 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 are applying the recently published third round of the Bangladesh Integrated Household Survey (BIHS) (2018–2019) with the other two rounds (2011–2012 and 2015) to estimate the benefits of solar power adoption. We tried to cover the United Nations Development Programme's three dimensions of the Human Development Index such as economic, educational, and health. In addition to economic, educational, and health outcomes, we have 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 determine which factors are playing 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.

This study contributes in three ways. First, it displays how solar adoption is connected to the rural employment structure. Second, it explains the association between solar electrification and the nutritional outcome of under-five children. Finally, it provides new estimates of economic, environmental, and educational outcomes with three waves of BIHS data.

This study found that the education of the head of household, wealth status, number of households, log of total land holdings, presence of sanitary latrine and remittance holder in the household positively associated with solar adoption, whereas the male head of household and electrification status of the community have a negative relationship. In the case of welfare analysis, both the propensity score matching (PSM) and the ordinary least square (OLS) estimates show that solar adoption has a positive relationship between income, expenditure, asset formation, children's education, and health. Also, it is replacing dirty fuel and increases the use of gas and liquefied petroleum gas (LPG). Further, solar electrification is associated with the changes in rural employment structure by reducing dependence on sharecropping and accepting alternative self-employment, such as trading business for men and poultry farming for women.

The remainder of the paper is structured as follows. The second section will discuss the literature on the welfare gained from solar adoption. The third part will show the conceptual link between solar adoption and welfare outcomes used in the paper. The fourth and fifth sections focus on methods, data, and some bivariate results. The sixth section illustrates the results and relevant discussions. Finally, the seventh and eighth sections cover the limitations and conclusion of this study.

II. LITERATURE REVIEW

This section highlights the important aspects that influenced the adoption of SHS in various countries and how they make impacts individuals' life 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. Moreover, how the SHS contributes to children's and women's lives.

A. Solar Adoption and Satisfaction

A range of social, demographic, and institutional factors, including the government's approach to rural electrification, influence family adoption of solar energy in Indian villages (Mishra and Behera 2016). According to Best and Saba (2021), financial assets are more essential than income and nonfinancial assets for a household's solar adoption. In addition to household income, solar adoption is influenced by kerosene consumption, the number of children, indoor pollution concerns, and the necessity for electric lighting in Bangladesh (Komatsu et al. 2011).

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 Sri Lankan experience, providing solar system maintenance training by service workers improves user satisfaction (Wijayatunga and Attalage 2005).

B. Solar and Economic Outcome

Solar energy influences economic productivity in Kenya (Jacobson 2007) and enables people to open new businesses in India (Buragohain 2012). According to Mishra and Behera (2016), fisherfolks can perform fishing for longer hours in rivers and seas and earn more than before adopting the solar system. In the case of Bangladesh, solar system adoption increased spending by about 4%, whereas raised income by up to 12%. In addition, an additional year of solar usage raises household per capita income by about 3% and per capita spending by roughly 2% (Khandker, Samad, Ali et al. 2014). Other studies also found SHS as an income-generating catalyst in Bangladesh's rural communities (Sharif and Mithila 2013), whereas some studies found that the income effect is negligible (Rahman and Ahmad 2013).

C. Solar and Environmental Outcome

Solar home-lighting systems have significantly reduced kerosene consumption in Indian homes (Buragohain 2012). According to Khandker, Samad, Sadeque et al. (2014), 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 to create solar panels and batteries can harm the environment if they are not properly disposed of once their useful life has gone (Khan 2019).

D. Solar and Child Education

The solar home lighting system significantly improved school-aged children's educational performance in India (Buragohain 2012). According to Mishra and Behera (2016), children used to go to bed early because of a lack of light, which hampered their educational outcomes. 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 enrollment (Khandker, Samad, Sadeque et al. 2014).

E. Solar and Health Outcome

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, according to (Samad et al. 2013), lowers the morbidity of women and children from respiratory disorders. 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).

F. Solar and Women's Life

The usage of SHSs in India increased working hours, notably for women (Barman et al. 2017). Mishra and Behera (2016) mentioned that solar improved women's life by making a better indoor place for living and working extended and productive hours, such as operating a sewing machine and performing stitching-related chores at night. Solar system adoption empowers women in a variety of ways, including mobility and various decision-making capacities that women can exercise on their own. Solar system adoption increases their parent's home visits, helps parents make decisions about their children and families and buy personal and household products, and adopts family-planning issues. In addition, they also found that, in comparison to their non-SHS counterparts, women in SHS homes spend less time collecting fuel and more time tutoring children (Khandker, Samad, Sadeque et al. 2014; Samad et al. 2013).

G. Solar and Recreational Outcome

Solar power is more closely associated with television, radio, and cell phone charging (Jacobson 2007). Improved access to energy through solar systems provides largely recreational and leisure benefits in rural Bangladesh (Rahman and Ahmad 2013).

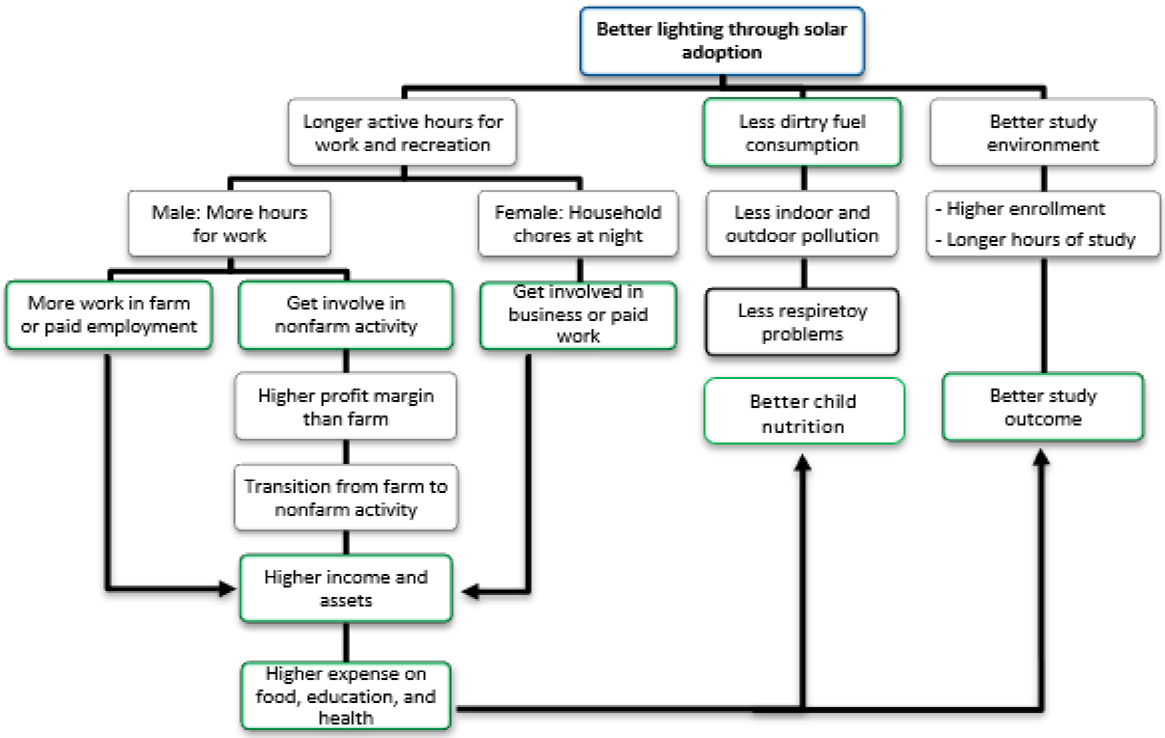
III. CONCEPTUAL FRAMEWORK

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. Adoption of solar energy mostly benefits through improved lighting which results in three immediate gains: allowing people to work productively at night, replacing dirty fuel like kerosene, and creating a better study environment. Since women may now complete their domestic work at night, they also engage in self-employment or hired labor, while men can use their spare time to engage in nonfarm business activities like operating part-time shops and 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, as solar lighting is more effective than conventional kerosene lamps, it directly replaces the usage of dirty fuels. The learnings from the substitution of kerosene through improved indoor air quality and decreased hassles of managing traditional lamps also contribute to other indirect benefits. For instance, solar adopter families replace traditional cooking fuel or materials such as firewood, coal, cow dung, and dried leaves with clean fuels (i.e., gas/LPG) as they also produce enormous indoor and outdoor pollution and bring a variety of respiratory diseases and gastrointestinal conditions.

Besides, solar electrification enables family members to watch television and utilize social media on their phones, which provide access to news and information about hygienic practices and health-related awareness. Such knowledge could assist moms in raising their children well and maintaining their health. If solar adoption improves the economic condition, then the household can feed their children nutritional food which limits malnutrition like stunting and underweight.

Figure 9: Welfare Dynamics of Solar Adoption



Economic outcome: Higher income, food and nonfood expenditure, asset value.

Employment outcome: Higher employment, employment in nonfarm sector, transition from farm to nonfarm sectors.

Environmental outcome: Reduction in dirty fuel use (such as kerosene).

Educational outcome: Higher enrollment, more years of education, better academic outcome, increased expenditure on education.

Health outcome: Better child nutrition, less respiratory issues.

Source: Conceptual model developed by authors.

IV. METHODS

This study aims to find both determinants and welfare gains of solar adoption. At first, we used both the linear probability model (LPM) 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 $s_{it} = 1$, then the model is

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

where X_{it} represents the demographic, economic, and community-specific characteristics. 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. We estimated the following OLS model:

$$\boldsymbol{Welfare_{it} = \beta_0 + \beta_1(Solar)_{it} + \beta_2} \ (\mathbf{Demographic})_{it} + \boldsymbol{\beta_3}(\mathbf{Economic})_{it} + \boldsymbol{\beta_4}(\mathbf{Community})_{it} + \boldsymbol{u_{it}} \dots \dots \dots \ \mathbf{(2)}$$

where i represents the individual respondents, t stands for time (i.e., 2011–2012, 2015, and 2018–2019) and u_i is the error term. The coefficient of solar gave us the idea of the degree of association between welfare outcome and solar adoption. The specific welfare equations are as follows:

$$\textbf{Economic}_{it} = \boldsymbol{\beta_0 + \beta_1(Solar)_{it} + \beta_2(Demographic)_{it} + (Economic)_{it} + (Community)_{it} + u_{it}}$$

$$\textbf{Employment}_{it} = \boldsymbol{\beta_0 + \beta_1(Solar)_{it} + \beta_2(Demographic)_{it} + (Economic)_{it} + (Community)_{it} + u_{it}}$$

$$\textbf{Environment}_{it} = \boldsymbol{\beta_0 + \beta_1(Solar)_{it} + \beta_2(Demographic)_{it} + (Economic)_{it} + (Community)_{it} + u_{it}}$$

$$\textbf{Education}_{it} = \boldsymbol{\beta_0 + \beta_1(Solar)_{it} + \beta_2(Demographic)_{it} + (Economic)_{it} + (Community)_{it} + u_{it}}$$

$$\textbf{Nutrition}_{it} = \boldsymbol{\beta_0 + \beta_1(Solar)_{it} + \beta_2(Demographic)_{it} + (Economic)_{it} + (Community)_{it} + u_{it}}$$

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.

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 analyzed 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 nonfarm 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 have adjusted the monetary data for inflation (i.e., with consumer price index data published by the Bangladesh Bank).

Years of education are calculated based on students' completed years of schooling. In the case of secondary enrollment, in Bangladesh, secondary education starts at grade 6 and continues up to grade 10. Students aged 11 years generally enter secondary school. Thus, we calculated secondary enrollment for 11 years old 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 heigh-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**. The standard errors are clustered at the village level during estimation.

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

Source: Authors' calculations.

V. 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. However, those households that do not use electricity as their primary lighting source (such as solar and kerosene) are only taken in our analysis. Therefore, 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. The number of observations declined over the years as Bangladesh has taken massive electrification projects to electrify every house within 2021 and, therefore, the number of non-electrified houses decreased from 2011 to 2019. The descriptive statistics of data are presented in **Table 2**.

Table 2: Summary statistics of the variables

Variables	N	Mean	Std. Dev.	Min	Max
Sex of Head	6,712	0.819279	0.384816	0	1
Age	6,712	44.97765	14.14981	17	93
Age Squared	6,712	2,223.176	1,394.998	289	8,649
Education of household head	6,712	2.478993	3.439388	0	22
Household size	6,712	4.158224	1.648973	1	17
Log of the total land	6,712	3.469384	1.559071	0	8.036897
Remittance	6,712	0.026371	0.160247	0	1
Loan	6,712	0.671484	0.469709	0	1
Shock	6,712	0.497765	0.500032	0	1
Wealth index	6,712	2.63826	1.402772	1	5
Year	6,712	2013.465	2.725337	2,011	2,019
Community electrification status	6,712	0.694875	0.460495	0	1
% of electrified household	6,712	31.69918	30.20083	0	96.42857
Bazar within community	6,712	0.404201	0.490773	0	1
Concrete road within the community	6,712	0.357569	0.47932	0	1
Motor-based public transport to go to town	6,712	0.513707	0.499849	0	1

Source: Bangladesh Integrated Household Survey 2018–2019, 2011–2012, and 2015.

The association between the outcome variables and SHS adoption status is 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.

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 nonfood 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)	

Source: Authors' calculations.

Table 4: Bivariate Analysis of Occupational Outcomes

	2011 Solar		P-value	2015 Solar		P-value	2019 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)	

Source: Authors’ calculations.

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)	

Source: Authors' calculations.

Table 6: Bivariate Analysis of Educational Outcomes

	2011 Solar		P-value	2015 Solar		P-value	2019 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)	
Enrollment 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)	
Enrollment 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)	

Source: Authors' calculations.

Table 7: Bivariate Analysis of Nutritional Outcomes

	2011 Solar			2015 Solar			2019 Solar		
	Yes	No	P-value	Yes	No	P-value	Yes	No	P-value
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)	

Source: Authors' calculations.

VI. RESULTS AND DISCUSSION

A. Factors Influencing the Solar Adoption

Solar is one of the electrification for households in hard-to-reach areas. Government and nongovernment organizations also extend their institutional support to underprivileged areas. Besides that, several socioeconomic and demographic factors also play crucial roles in adopting solar. As solar adoption is a dichotomous variable (where one represents solar adoption and zero otherwise), we saw both the OLS/linear probability model (LPM) and the marginal effect of the probit model (**Table 8**). We 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.

Table 8: The Determinants of Solar Adoption

Variables	(1) OLS (LPM)	(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)

Variables	(1) OLS (LPM)	(2) Probit (Marginal Effect)
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)
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

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

Source: Authors' calculations.

B. The Effect of Solar Electrification on Economic Outcome

Solar electrification increases illumination quality compared to traditional lighting methods such as candles and kerosene lamps. It may encourage households to work longer hours or engage in trading or other income-generating business, which can increase household income. Moreover, solar energy can boost household income by giving members of the household access to news and information via electronic media like television and radio. With higher income, households like to live a better life and, therefore, the household food and nonfood expenditure also might rise.

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 nonfood 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, Samad, Ali et al. (2014) 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, Samad, Sadeque et al. (2014) is based on cross-section data collected in 2012.

Table 9: The Effect of Solar Electrification on Economic Outcome

Methods	(1) Log of Total Income	(2) Log of Total Expenditure	(3) Log of Food Expenditure	(4) Log of Nonfood Expenditure	(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)

Methods	(1) Log of Total Income	(2) Log of Total Expenditure	(3) Log of Food Expenditure	(4) Log of Nonfood Expenditure	(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)

*** 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.

Source: Authors' calculations.

C. The Effect of Solar Electrification on Employment Outcome

In the short run, solar adoption might change employment transition, especially in self-employment. 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. In the long run, they might permanently leave agricultural activity and get involved in solar-based profit-making businesses.

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.

We also applied the multinomial model in the appendix **(Appendix Table)** for robustness check, as the employment categories are unordered categorical variables. We check the association between solar adoption and employment with and without adjusting the controls and found to some extent, similar results as the original, which confirms the relationship.

Table 10: The Effect of Solar Electrification on Employment Outcome

Methods	(1) Male: Share-cropping	(2) Male: Poultry Farming	(3) Male: Trading Business	(4) Female: Share-cropping	(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)
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 neighbour)	-0.037***	0.001	0.026**	0.006	0.076***	0.008
	(0.010)	(0.004)	(0.011)	(0.004)	(0.015)	(0.005)

*** p<0.01, ** p<0.05, * p<0.1, 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.

Source: Authors' calculations.

D. The Effect of Solar Electrification on Environmental Outcome

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 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. 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.

Table 11: The Effect of Solar Electrification on Environmental Outcome

Methods	(1) Log of Kerosene Expenditure	(2) Log of Agri-fuel Expense	(3) Log of Gas/LPG Expenditure
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)

Methods	(1) Log of Kerosene Expenditure	(2) Log of Agri-fuel Expense	(3) Log of Gas/LPG Expenditure
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)

*** p<0.01, ** p<0.05, * p<0.1, LPG = liquefied petroleum gas, 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.

Source: Authors' calculations.

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.

Khandker, Samad, Sadeque et al. (2014) found that solar adoption reduced monthly kerosene consumption by 2 litres. Cabraal et al. (2021) and Buragohain (2012) also found similar results. Our dataset did not provide the amount of kerosene consumption in litres but the amount of expense on kerosene. Nevertheless, our results provide a similar indication that kerosene consumption was reduced among solar households.

E. 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 enrollment rate decreased among SHS homes compared to non-SHS, although boys' secondary enrollment showed a positive influence among SHS families. According to Khandker, Samad, Sadeque et al. (2014), solar adoption had increased the children's years of schooling and school enrollment in Bangladesh, which, to some extent, provides a similar result to our study.

Table 12: The Effect of Solar Electrification on Educational Outcome

Methods	(1) **Boys: Years of Education**	(2) **Girls: Years of Education**	(3) **Boys: School Enrollment**	(4) **Girls: School Enrollment**	(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)
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)

*** p<0.01, ** p<0.05, * p<0.1, 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.

Source: Authors' calculations.

F. The Effect of Solar Electrification on Nutritional Outcome

The use of solar instead of kerosene for illumination minimizes home air pollution, which poses significant health risks to children 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. 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.

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 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.

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)

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)
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)
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)

*** p<0.01, ** p<0.05, * p<0.1, haz = heigh-for-age z-score, HH = household, OLS = ordinary least square, PSM = propensity score matching, waz = weight-for-age z-score.

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.

Source: Authors' calculations.

VII. LIMITATION

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. Secondly, the findings apply to households who live in rural areas and do not use electricity as their main lighting source. So, it is not easy to generalize the result for the whole Bangladeshi population.

VIII. CONCLUSION AND POLICY SUGGESTIONS

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 nonfarm activities such as trading businesses, and females are doing poultry farming. These income-generating activities create opportunities for more expenses in food and nonfood expenditure and asset formation. Therefore, the study reveals that SHS households are investing more in their child education and improving the nutritional status of under-five children.

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 labor force in Bangladesh is employed in the agriculture sector, there might be enough potential for solar irrigation pumps and other solar-based agrotechnology. Further, 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. 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.

APPENDIX

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

Appendix Table: The Effect of Solar Electrification on Employment Outcome
(Multinomial Regression Model**)**

	(1) Male: Share-cropping	(2) Male: Poultry Farming	(3) Male: Trading Business	(4) Female: Share-cropping	(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)

*** p<0.01, ** p<0.05, * p<0.1.

Notes:

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.

Source: Authors' calculations.

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Social Benefits of Clean Energy

Evidence from Bangladesh

Using the three rounds of the Bangladesh Integrated Household Surveys, this study attempts to quantify the welfare effects of solar adoption. We discovered that solar adoption is connected with increased income, expenditure, and asset value growth, as well as a significant decrease in kerosene expenditure compared to non-adopters. Other findings include that solar households tend to abandon sharecropping in favor of trading and poultry farming, and that children in solar households benefit in terms of schooling and nutrition.

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