Doctoral Dissertation

Electrification with Solar PV Technology and its Implication to Educational Outcome: Empirical Evidences from South Asia

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Dedication

To my respected parents, my wife, and my son who have been my constant source of inspiration.

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List of Abbreviations

AMCE	average marginal component effect
ATE	average treatment effect
ATET	average treatment effect on the treated
BBS	Bangladesh Bureau of Statistics
BDT	Bangladeshi taka (currency)
BEV	battery electric vehicle
BPDB	Bangladesh Power Development Board
CDF	cumulative distribution function
CEM	coarsened exact matching (method)
CIA	conditional independence assumption
CREDA	Centre for Rural Education and Development Action (India)
DID	difference-in-difference
ECP	external choice probability
EV	electric vehicle
FE	fixed effect
GDP	Gross Domestic Product
GPA	grade point average
HDI	Human Development Index
HH	household head
ICP	internal choice probability
ICT	information and communications technology
IDCOL	Infrastructure Development Company Limited (Bangladesh)
IPW	inverse probability weighting
IT	information technology
IV	instrumental variable
kgoe	kilogram oil equivalent
LDC	least-developed country
LPG	liquefied petroleum gas
MICS	Multiple Indicators Cluster Survey (Bangladesh)
MS	Microsoft
NA	non-attendance
NGO	non-governmental organization
NNM	nearest neighbor matching (method)
OLS	ordinary least squares
PBS	*Palli Bidyut Samity*

PDF	probability distribution function
PPP	purchasing power parity
PSM	propensity score matching (process)
PV	photovoltaic
RCA	randomized conjoint analysis
RCT	randomized control trial
REB	Rural Electrification Board (now Bangladesh Rural Electrification Board)
SATT	sample average treatment effect on the treated
SDG	Sustainable Development Goal
SE	standard error
SHS	Solar Home System (program)
Si	silicon
UN	United Nations
UNDP	United Nations Development Programme
UNICEF	United Nations Children's Fund
UNO	*Upzilla Nirbahi* Officer
WB	World Bank
WHO	World Health Organization

Executive Summary

Access to electricity is an essential component of modern life that enhances people's living standard. We cannot sustain our comfortable lives without electricity. Increased electricity supply improves education, recreation, health, comfort, protection, and productivity. However, a significant portion of people – mainly concentrated in sub-Saharan Africa and South Asia – live every day without electricity. This scenario is a fundamental obstacle to the progress of a significant proportion of the world's population and affects a wide range of development indicators, including health, education, food security, gender equality, livelihoods, and poverty alleviation. Firstly, this study examined the impact of grid electrification on school enrollment in Bangladesh in the short run as well as the long run. Secondly, the study investigated the impact of a solar home system on educational outcomes in rural Bangladesh. Thirdly, the study examined consumers' preferences for an organic solar photovoltaic (PV) system based on a conjoint analysis in rural India.

In the first section, this study aimed to show the impact of access to electricity on school enrollment in Bangladesh. It offered an empirical investigation of the relationship between access to electricity and school enrollment status, such as grade progression, grade repetition, and non-attendance. The data were taken from Bangladesh's Multiple Indicators Cluster Survey (MICS) database from 2012–2013, as provided by the Bangladesh Bureau of Statistics (BBS) and the United Nations Children's Fund (UNICEF): the data include two years of grading information for children aged from 5–15. The study applied propensity score matching (PSM) and the Markov schooling transition model using matched sample data. The results showed that access to electricity has a significant positive effect on grade progression and a significant negative effect on non-attendance in both the short run and the long run. The simulation result showed that the non-attendance rate is lower and the school enrollment rate for children in grades 9–11 is higher in electrified areas compared to unelectrified areas. This result suggests that access to electricity is an important strategic indicator for increasing school enrollment in both primary and secondary schools.

In the second section, this study examined the impact of a solar home system (SHS) on a student's academic performance and school enrollment in rural Bangladesh. Data came from a

random cluster sample of 673 children who had access to an SHS and 1023 children who did not, with all children being from Rahumari *upzilla*, Kurigram district, Bangladesh. Coarsened Exact Matching (CEM) method was applied to correct for selection bias in observable characteristics. The study found that the SHS has a significant positive effect on a student's grade point average (GPA) as well as on receiving a scholarship. It also had a significant positive effect on grade progression and a significant negative effect on dropping out. No significant effect of the SHS was found on grade repetition and out-of-school students. The study concluded that promotion of SHS adoption among un-electrified areas is needed and should be a priority to improve children's academic performance and school enrollment by ensuring universal education for all children.

In the third section, this study examined consumers' preferences for an organic solar PV system. In rural areas, poor people are used to having a silicon or conventional solar PV system. They keep their existing system and face difficulty in accepting new technology. In the study, the organic solar PV system was illustrated to rural people, with its function explained to enhance their understanding. This type of demonstration plays an important role in decision making when choosing an appropriate solar home system (SHS). Some features, such as the solar panel appearance, size, color, surface pattern, functional performance, and price are considered to be the most visual elements in the presentation when respondents are making their choice. The study's intervention involved showing a picture of the organic solar PV system of a different size in one group, while in the other group, the features of the organic solar PV system were explained verbally. The study found that consumers preferred the flexible solar PV system over the rigid conventional PV system.

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Chapter 1: Introduction

Modern energy services are critical for ensuring people's quality of life and promoting economic development. While also protecting ecosystems, access to energy is at the heart of issues such as security, climate change, food production, and economic strengthening. Increased electricity supply improves education, recreation, health, comfort, protection, and productivity. A significant portion of people – mainly concentrated in sub-Saharan Africa and South Asia – live every day without electricity. This scenario is a fundamental obstacle to the progress of a significant proportion of the world's population and affects a wide range of development indicators, including health, education, food security, gender equality, livelihoods and poverty alleviation. One case study showed that electricity consumption is significantly correlated with per capita gross domestic product (GDP) and Human Development Index (HDI) scores in 120 countries and that a high level of per capita electricity consumption is related to a high level of economic activities [1]. Ensuring access to electricity has promoted all development, although 1.3 billion people in our global society are still unable to access electricity [2]. In addition, most of these people live in the rural areas of developing countries, which are often isolated, sparsely populated, and have poor infrastructure and services. In dispersed and remote villages, grid electrification is expensive, which may challenge the financial viability of electricity utilities. In this case, people are increasingly considering how to achieve the goal of universal access to energy, emphasizing that the role of rural electrification and off-grid small-scale power generation are two of the most appropriate choices. The benefits of electrification programs in most developing countries are the savings made by households turning to cheap, clean, safe and reliable electric lighting, with electricity also used for entertainment and cooking rather than using expensive batteries, candles, and kerosene.

The Human Development Index (HDI) measures enrollment and literacy as indicators of education, life expectancy as an indicator of health care, while human development is measured by per capita GDP (measured by purchasing power parity [PPP]). The use of locally available high-quality energy has been found to increase the HDI value by 16–18% from the original figure [3]. The use of high-quality energy resources has three impacts: reducing pollution emissions during heat and lighting transitions, improving energy security, and improving income-generating activities. Most households in rural areas use kerosene as a source of light. The potential for solar photovoltaic (PV) power generation is enormous, as it can solve problems such as power outages, indoor pollution, and carbon emissions. The current study examines the potential impacts of access to electricity on an educational outcome that is one of the important HDI indicators. Quality of lighting also enhances productivity that, in turn, contributes to the regional economy. People in off-grid areas always have to face choosing reliable energy for the purposes of lighting and cooking. Renewable energy is a viable option for meeting the essential energy needs of rural low-income people. It is crucial to identify the impact of solar PV systems on educational outcomes in rural areas. Over the decades, the technological innovation of solar home system (SHS) packages in rural Bangladesh has been observed. The current study seeks to investigate the preferences of consumers living in disadvantaged regions for solar home systems (SHSs).

Most studies have shown the impact of rural electrification on income, health, and education. Electricity-connected households have benefited in terms of income, education, and agricultural productivity. One study found that the impact of electricity on income can be measured directly or through the intermediaries of education, health, and agricultural productivity [4]**.** The ways in which electricity contributes to the productivity of rural populations are diverse. Electricity services improve the provision of health and education services by providing lighting, cooling, heating, and modern communications. A household with an electricity connection is more engaged in home business activities than a household with no electricity [5]**.** The United Nations (UN) *2030 Agenda for Sustainable Development*, adopted in September 2015, includes the goal of ending global energy poverty through a universal approach that provides affordable, reliable, sustainable and modern energy for all. In the academic literature, rural electrification (defined as the percentage of the rural population with access to electricity) is considered an important component of socio-economic development [6]. Per capita income, national savings, and population density may further promote rural electrification, while a high level of additional aid, GDP and rural population ratios may pose challenges to equality [7].

The lack of modern energy services is one of the reasons for poverty and low economic development. Of Bangladesh's population of 161 million, nearly 75% lives in rural areas. In the past decade, Bangladesh has made commendable progress in the education sector. More than

90% of children eventually attend school, with almost no difference now between attendance by boys and girls. Health and nutrition inputs are often included in education sector strategy as health and malnutrition are known to affect children’s learning ability. The government of Bangladesh has launched a school feeding program and a female stipend program to reduce the number of out-of-school students in Bangladesh. Poor quality lighting is also another barrier to children’s education. Even in the near future, some remote areas in Bangladesh cannot obtain grid electricity. Rural electrification will help achieve social and economic development. Improving electricity supply can influence rural industries, increase agricultural productivity, and provide children with more effective study time at night [8]. In 2016, the total number of consumers linked to the grid was 21.8 million. These 21.8 million domestic connections (families) accounted for about 50% of all Bangladeshi households. Another 15% of households could use off-grid electricity. Ensuring access to electricity for all is a significant challenge due to resource and technology constraints.

As electricity is a suitable form of energy for lighting, its provision is expected to relate to the use and level of clean lighting in electrification within a country. The lack of electricity access hinders development. It affects everything from people’s learning ability to the ability to develop industries and provide public services, such as health care. This was shown in a study that reviewed the barriers to energy development, the contributing factors and impacts, and the essential welfare impacts of electrification in rural areas [9]. Most developing countries are lagging behind the UN’s goal of achieving universal access to electricity in 2030. The Sustainable Development Goals (SDGs) agenda has set ambitious goals to accelerate the pace of establishing foundations for human development. Some of these goals include improving people’s living standards at home, such as the provision of access to electricity and clean cooking energy, and improving water and sanitation. However, the millions of households in developing countries that still do not have access to clean, reliable, safe and modern energy services provided at reasonable prices, continue to pay high costs for inferior alternatives. This situation exacerbates poverty, undermines health, limits the availability of local services, increases vulnerability to climate change, limits opportunities, and erodes environmental sustainability at the local, national, and global levels, having a negative impact on education and health.

This study has added to the literature on the impact of rural electrification on developing countries. In previous studies, researchers have investigated various aspects of the socio-economic impact of rural electrification. This existing research supports the hopes of multiple interests, mainly based on evidence from Asia and Latin America. A considerable number of case studies have highlighted the link between access to electricity and different socio-economic variables [10]. The effects most often highlighted are: educational benefits, due to increased learning time; increased non-agricultural activities, leading to increased income; and reduced rates of respiratory disease due to reduced use of kerosene. In addition, high levels of poverty, lack of effective development programs, limited policy resources, and weak institutional arrangements have contributed to low levels of access to energy in rural areas.

One study has sought to reveal the relationship of access to electricity and rural areas in developing countries, with regard to access to electricity and its impact on socio-economic conditions. That study has pointed out that multidimensional aspects of poverty, such as the economy, education, and health, have received increasing attention, with access to modern energy sources, such as electricity, being a possible solution [11]. Energy access has traditionally been one of the core aspects of economic and social development. It is also closely related to the urgent issue of energy justice, involving everyone's access to energy services and associated social benefits, regardless of whether they live in developing or developed countries. The current study has sought to explore the effect of electrification on educational outcomes and school enrollment in rural areas in a developing country. Although a large body of literature is available on different aspects of energy in developing countries, a serious lack of research is evident on the impact of electrification on specific educational outcome. Therefore, this issue is of sufficient importance to warrant further investigation. In the current case, the purpose of this literature review is to investigate electrification's rural prospects, progress, impact, and challenges as documented in prior research. The review begins with a description of Bangladesh's specific energy-related discussions on energy consumption scenarios and then discusses the effects of electrification on school enrollment and students' academic performance.

As shown in previous reviews, many studies have found the two-dimension nexus of electrification, that is, its economic and social dimensions. It is argued that electrification and local economic development are complementary, with electrification considered as the fuel for rural economic development. Studies have highlighted that the framework conditions necessary for the provision of energy services to rural communities must be identified, and that energy access must be translated into improved rural development outcomes [12]. The impact of electricity on the local economy is believed to be a cross-cutting dimension, with household electrical lighting reducing the use of kerosene, thereby reducing and improving households' indoor air pollution. The importance of mitigating energy poverty in rural areas and its impact on the economy cannot be underestimated. Energy poverty is a severe and growing problem involving indoor air pollution, personal injury during fuelwood collection, and lack of public health care. Energy poverty affects the roles of both genders in society, as well as educational opportunities for children and adults [13]. The problems faced by rural people in obtaining safe, clean, and reliable energy supply are not minor inconveniences. Instead, these are significant obstacles to rural economic development and social well-being. A multifaceted approach to solving rural energy problems is not only justified but also essential.

The direct benefits of electrification come from improving lighting, promoting extended learning and reading time, and assisting with other housework, thus helping to improve educational achievement. The causal relationships between electrification and educational outcomes as well school enrollment are complex. The existing literature has focused on the impact on socio-economic development of rural electrification and electricity use. A World Bank working paper, verifying research methods, findings, and robustness, reported the close link between energy, economic growth and poverty reduction [14]. Rural socio-economic development and feedback on various social and economic changes via electrification cannot be adequately estimated. Most energy access impact assessments assume that energy access has linear, one-way effects. However, predictions are rarely consistent with reality and, at times, indirect benefits could not be reflected. From a modeling perspective, lack of attention to causality's dynamic complexity may mean that previous studies' estimation results may be misleading. To improve the causal-effect relationships and to find the solution, the current study conducted a comprehensive review and extensive analysis of the literature.

The Solar Home System (SHS) program has become the primary tool for providing electricity to people living in rural areas in Bangladesh. The main reason for the successful adoption of the SHS program is that it is focused on meeting the needs of the family and has the ability to make the system as affordable as possible [15]. Electrification with a solar PV system has many direct and indirect benefits that ensure environmental sustainability. Reducing the use of kerosene is the main impact of the SHS which reduces pollution, improves light quality, and increases lighting time at night, thus reducing the workload involved in cleaning kerosene lamps [16]. Those who were using traditional fuels for small business activities can switch to solar lights and increase their income due to extended working hours at night. Women and children enjoy greater benefits due to the quality of light facilities in their homes. Women feel comfortable doing household work and children can study in the evening. With the use of kerosene lamps and wicks, people are increasingly worried about fire hazards and indoor air pollution [17].

The current study sought to examine the impact of lighting from the grid on school enrollment as well as the impact of lighting from the SHS on educational outcomes and school enrollment in Bangladesh. Many studies have shown impact analyses of rural electrification on income, education, and health in developing and developed countries. No specific study has been undertaken on the impact of good quality lighting on school enrollment and educational outcomes. Renewable energy is a key component of development, and Bangladesh has made significant progress in covering most of the country's population, in urban and in rural areas. Change in technological innovation and in the SHS package is also seen in Bangladesh. Consumer demand for the SHS changes with changes in price and in some essential features of the existing package. Solar photovoltaic (PV) technology brings enormous potential and benefits to society. At the present time, a variety of materials are emerging in the PV market. In rural areas, it is often difficult to purchase and transport kerosene fuel. The brighter SHS lamps are also a massive improvement of the poor light provided by kerosene lamps. With SHS lighting facilities, students spend more time learning, and women no longer rely solely on the sun for housework. Lighting is also beneficial for other family activities, such as women sewing, social gatherings after dark, etc. Solar power also helps local businesses, such as small shops and village markets, to operate at night, as well as assisting irrigation facilities. However, improving efficiency is one of the critical factors in establishing PV technology in the market. The current study tests consumers' preferences for organic solar PV systems in Chhattisgarh, India, based on a randomized conjoint analysis. This study identified major potential benefits, such as organic PV systems, efficiency, the system lifetime, and customer involvement in implementing solar lighting systems for the poor. The study aimed to find out the investment, promotion and appropriate business model to use to enhance the quality of life for poor people.

The current study aimed to overcome the fundamental limitations of many existing studies that failed to address the problems of endogeneity. Furthermore, the study sought to determine the impact of access to electricity on school enrollment in Bangladesh and the impact of the SHS on educational outcomes. The study used rigorous econometric techniques to analyze data from the cross-sectional Multiple Indicators Cluster Survey (MICS) of households in Bangladesh from 2012–2013 and primary data of children with and without SHSs, as collected in 2018. The study also collected data from India in 2017 to examine consumers' preferences for future organic solar PV systems. As discussed later in this study, electrification has benefits in alternative ways, such as children's education. This study does not analyze the effects of individual factors that contribute to welfare benefits.

The study applied the Markov school transition model to conduct a disaggregated evaluation of the impacts of access to electricity on children's school enrollment in Bangladesh. This modeling approach allowed for a more complete analysis of the impacts of electrification than a focus on enrollment rates alone, as found in most previous studies. Comparisons of educational transition matrices estimated for treatments and controls revealed that electrification has a beneficial impact on the educational accumulation process, with statistical tests rejecting the hypothesis of zero impact of electrification for most ages. The SHS has improved the quality of life and created opportunities for new income-generating activities, such as cell phone charging, small businesses, watching TV, night work, and enjoying the lighting quality. The student with access to electricity through an SHS is associated with better grade progression, a lower grade repetition rate, and a lower rate of non-attendance. The impact of SHSs on educational outcomes is positive, while their impact on school enrollment is mixed. Consumers in Bangladesh preferred the low watt peak SHS at a convenient price. Consumers in rural India chose the solar PV system which works in cloudy weather conditions.

The structure of this PhD thesis is as follows. Chapter 2 presents the effects of electrification on school enrollment in Bangladesh. Chapter 3 shows the impact of a solar home system (SHS) on educational outcomes in rural Bangladesh. Chapter 4 discusses the conjoint analysis of consumers' preferences for a future organic solar PV system, and Chapter 5 concludes the thesis.

Chapter 2: Effects of Electrification on School Enrollment in Bangladesh: Short- and Long-Run Perspectives

2.1 Introduction

Lighting is a basic human need and is also considered an important indicator of everyday lifestyle. Changes in lighting also change people's performance. Several mechanisms contribute to increasing human performance through improved lighting, such as visual performance, visual comfort, interpersonal skills, problem solving, and change processes [18]. Lighting also has non-visual effects. Good quality lighting affects performance, mood, attention, and synchronization [19]. Most households in unelectrified regions use kerosene lamps, candles, and solar lanterns as sources of indoor lighting. These types of lighting adversely affect the safety, health, and environment of household members. Access to electricity is regarded as access to lighting sources. The current study extends reflection on the link between access to electricity and school enrollment. It is motivated by an empirical study based in rural Mexico which showed that a school subsidy program was associated with higher enrollment rates, less grade repetition, better grade progression, and lower dropout rates [20]. Moreover, the limited studies conducted in several developing countries have shown the effects of access to electricity on children's education in terms of study time and school attainment. The current study sought to examine the effects of electrification on school enrollment (grade progression, grade repetition, and non-attendance) in both the short run and long run.

Several assessments have been undertaken of the impacts of electricity on socio-economic development. Access to electricity reduces the time spent by children on activities such as gathering fuelwood and fetching water, promoting home study and enabling the use of educational media and communications at school [21]. A study by the United Nations Development Programme/World Health Organization (UNDP/WHO) showed that education enrollment ratios correlate with access to electricity [22]. One macro level study using panel data showed that long-run bidirectional causality exists between electricity consumption and five human development indicators: per capita GDP, consumption expenditure, urbanization rate, life expectancy at birth, and adult literacy rate [1]. Many researchers have shown a positive relationship between access to modern energy and economic development. Affordable and accessible modern energy plays an essential role in development and ensures sustainable development [23][24][25]. However, electricity and income exhibit two-way causality: income explains the potential to connect to electricity, and connection to electricity has a substantial and significant effect on income [26]. Empirical studies on electrification have generally supported the benefits to health, education, and income; however, these claims are weak [27][28]. Home electrification helps to improve children's education [29]. One study claimed that interactions between energy and development are complex and not causal [30]. The impact of electrification appears to increase the hours of work for men and women, in particular, increasing women's employment outside the home by releasing them from home production [31]. Dinkelman [31] applied two identification strategies, namely, instrumental variables and fixed-effect approaches, to overcome the endogeneity problem of electrification. The confounding trend of electrification makes it more difficult to identify the treatment effect on the economy. In the current study, it is assumed that no confounder is present in the study's model, and propensity score matching (PSM) is applied to identify the impact of electrification on school enrollment.

Household access to electricity has a significant positive impact on children's nutritional status as a result of the family's increased wealth. Children's nutritional outcomes are affected by causal channels such as wealth, fertility, and television [32]. One empirical study estimated the causal impact and showed that electrification has a significantly positive impact on household income, expenditure, and school enrollment in Bangladesh [33]. Another study based on country-level data from urban and rural Brazil showed that electrification has a substantial positive and significant effect on income, literacy, and enrollment rate components of education [34]. Furthermore, a study indicated that electricity from an SHS increases children's study time in Bangladesh [35]. The electrification of homes, schools, and communities has a significant effect on educational outcomes [36]; moreover, electrification has a positive effect on female enrollment in school and on reading capability for both boys and girls [37].

Bangladesh was the first country in the world to implement school incentive programs to increase school attendance, especially for children from low-income families. These incentives include free tuition, books, food provided in exchange for school attendance (Food for Education), and a stipend for female students. Over the past two decades, a significant proportion of education policies has been applied to increasing school enrollment through Food for

Education and stipends for poor students and female students. This type of education policy suggests that income is the primary barrier to children continuing their studies in school. The cash incentive program has a direct effect on school enrollment, and low-income families respond positively by sending their children to school. Evidence from descriptive statistics has shown that school incentive programs (Food for Education and female student stipends) in Bangladesh increase children's school attendance, and decrease the out-of-school rate and child labor activity [38]. Another study, based on descriptive statistics and a multivariate model, also showed that the Food for Education program increased school enrollment, promoting school attendance and preventing dropping out [39]. The motivation for the current study is to assess the impact of electrification on school enrollment. In Bangladesh, providing continuous electricity is a major problem, and load shedding is a common scenario in rural areas. Access to electricity has an indirect effect on children's study due to the quality of lighting. The current study seeks to examine the impact of access to electricity on school enrollment.

Education is an essential tool for strengthening human resources and maintaining steady development in any country. In Bangladesh, gross school enrollment has approached the universal level, and the primary school completion rate has remained at 60% since 2000 [40]. Grade repetition, non-attendance, and dropping out also remain as major problems. Some research has shown that dropping out occurs due to either financial problems or a lack of interest in education. Several factors potentially drive these causes such as age, gender, poor physical condition, geographical location, household characteristics, and economic hardship [41][42]. Study completion also relates to gender, family income, and the cost of school fees, books, uniforms, and transportation [43].

Several pathways can be followed to identify the possible causal impacts of electrification on school enrollment. Firstly, the use of electricity enhances the income opportunities of the household through extended work hours, and a greater income prompts parents to send their children to school to achieve a better future, based on the social and financial returns of education. Secondly, electricity can improve the lighting status of the household and replace traditional candles and kerosene lamps. Household electrification leads to a reduction in indoor air pollution [44]. This helps children to study longer and with better concentration. It also allows parents to take better care of their children by allowing more flexible use of time. Thirdly, access to electricity provides families with more, better quality information through information technology (IT) such as cell phones and television. It is possible to speculate that the benefits from access to electricity can be explained by these three causal channels, but the above causal impacts cannot be estimated due to the absence of data.

Most previous studies have used different ways to show the impact of access to electricity on education. This type of nexus states the positive benefit of electricity use on education without explaining the causal relationship. Some studies have reported correlations that appear to show the positive impact of electricity use, although multiple socio-economic factors might impact on education. The existing literature has also failed to capture the reverse causalities and the potential bias of access to electricity on educational outcomes. The potential drawbacks of studies in the existing literature are as follows: (1) most studies rely on correlations and (2) most studies adopt a single indicator, such as the enrollment rate, dropout rate, or grade repetition rate; thus, they cannot assess the long-run effects of electricity on school enrollment.

For the purpose of evaluation, the current study applied a propensity score matching (PSM) approach that captures different covariates for participation in a single propensity score. This study has adopted a non-experimental strategy to assess the impact of electricity on school enrollment in Bangladesh. Thus, by using panel data from the Multiple Indicators Cluster Survey (MICS) database, through PSM, it is possible to isolate the causal effect of access to electricity on school enrollment. The nearest neighbor matching (NNM) method was applied to estimate the impact of access to electricity, in which each treatment unit was matched to the comparison unit with the closest propensity score. The study constructed transition matrices for both groups based on age and took the difference to estimate the short- and long-run impact of access to electricity on school enrollment. The data analyzed in this study cover two years of information on grades of children studying in primary and secondary schools. Thus, it is impossible to assess the long-run impact due to the short time span of the data. However, the long-run impact is the study's key interest as access to electricity is an important indicator of socio-economic development. Therefore, the study proposes a method for simulating the effects through age transition matrices. The results, based on the study's simulation, indicate that if children are aged 5 when they begin attending school and continue to study to age 15, their school enrollment distribution would change substantially. Moreover, non-attendance would decrease by 2.48%, and transition to grade 11 would increase by 0.43% in electrified regions compared to unelectrified regions. The simulation results also show that a substantial impact of electrification on school enrollment occurs for grades 9–11.

The rest of the chapter is organized as follows. Section 2.2 provides the estimation methods, comprising the matching procedure and the Markov schooling transition model. Section 2.3 presents a description of the data. Section 2.4 provides the empirical results and discussion, while Section 2.5 presents the conclusion.

2.2 Estimation Methods

If access to electricity were randomly assigned to households, it would be an experiment. It would be possible to evaluate by household the causal effect of access to electricity on children's school enrollment as the difference in average school enrollment between those with and those without access to electricity. However, home electrification is based on self-selection by each head of the household instead of random assignment. The government electrification program is also influenced by political pressure, regional priority, and donors' attitudes [45]. Rich households enjoy more opportunity to install electrification compared to poor households. It can be said that the treatment assignment is not random and that a systematic difference exists between the group with electricity and the group without electricity. Selection bias could possibly occur as unobservable factors influence both the treatment and outcome variables. Hence, the application of the ordinary least squares (OLS) method would result in biased estimates. In the current study, the difference-in-difference (DID) method could not be applied as the study had one-shot data. However, the study could control for selection bias by employing an instrumental variable (IV) approach. Finding an appropriate instrument from the data set proved to be difficult [46].

Access to electricity could be considered a non-randomized treatment, with the treatment effect based solely on observable characteristics. The PSM estimator is a popular method among analysts, especially for social program evaluation. The current study sought to construct a transition matrix that would reveal the grade transition of children between the two groups; however, matched samples were needed to construct this kind of transition matrix. The PSM method assisted the study by grasping matched samples. The study then applied the Markov schooling transition model based on these matched samples. The short- and long-run impacts on school enrollment were thereby evaluated. However, the recent empirical literature has identified some bias in the PSM method [47] which is associated with factors including: selection of the unobservable; failure of the common support condition; failure to control for local differences; and selection of the dependent variable for both control and treatment groups [48].

2.2.1 Matching Procedure

It is possible to estimate the average treatment effect (ATE) in a counterfactual framework, in accordance with Rosenbaum and Rubin [49], as follows:

$$ATE = Y_i^{AE} - Y_i^{NAE} \tag{1}$$

where Y_i^{AE} and Y_i^{NAE}, respectively, denote school enrollment of children in a household that has access to electricity and children in a household that does not have access to electricity. As both Y_i^{AE} and Y_i^{NAE} are not normally distributed, the normal distribution equation can be expressed as follows:

$$Y_i = T_i Y_{iAE} + (1 - T_i) Y_{iNAE}\ T = 0, 1 \tag{2}$$

If P is considered as the probability of observing a household with access to electricity, that is, $T = 1$, the average treatment effect can be written as:

$$\begin{aligned} ATE = P \cdot [E(Y_{AE} | T = 1) - E(Y_{NAE} | T = 1)] + (1 \\ - P)[E(Y_{AE} | T = 0) - E(Y_{NAE} | T = 0)] \end{aligned} \tag{3}$$

Equation (3) indicates the effect of access to electricity on the entire samples. This is measured by the weighted average of the effect of access to electricity on both the treated sample and the control sample with each weighted by its relative frequency. It is not possible to estimate the causal inference of the unobserved counterfactuals, ($E(Y_{AE} | T = 0)$ and $E(Y_{NAE} | T = 1)$) [32].

An important issue in evaluating the impact of access to electricity on children's school enrollment is that it might not be possible to obtain counterfactual information from the existing data sets. The study sought to solve the problem by using the PSM method that enables the construction of a single propensity score from the pre-treatment characteristics [49]. It was then possible to use the propensity score for matching with scores from similar individuals. Based on the treatment, the PSM method, given the conditional pre-treatment variables, is calculated as follows:

$$p(X) = Pr[T = 1|X] = E[T|X];\ p(X) = F\{h(X_i)\} \tag{4}$$

where $F\{.\}$ can be normal or probit cumulative distribution, and X is a vector of covariate characteristics.

Two conditions need to be fulfilled, namely, the conditional independence assumption (CIA) and common support between the two groups. The matching method can be meaningfully applied over regions of common support (see Appendix Figure A1). A strong argument is that a person with the same propensity score should have the same X values, with a positive probability of being both in the treated and control groups [50]. The average treatment effect for the treated (ATET), based on propensity scores, can be estimated as follows:

$$\begin{gathered} ATET = E\{Y_{iAE} - Y_{iNAE}\ |T = 1\}, \\ ATET = E[E\{Y_{iAE} - Y_{iNAE}\ |T_i = 1, p(X)\}], \\ ATET = E[E\{Y_{iAE}|T_i = 1, p(X)\} - E\{(Y_{iNAE}|T_i = 0, p(X)\}|T = 1]. \end{gathered} \tag{5}$$

This indicates the average difference between those who are treated and their matching partners. A popular way to estimate the treatment effect is the nearest neighbor matching (NNM) method. In the current study, the treatment effect is estimated based on the propensity score, but not on the condition of all covariates. The covariate balancing between the treatment and control groups after matching needs to be checked (see Appendix Figure A2).

2.2.2 Justification of Covariate Selection

The determinants of household access to grid electricity comprise many factors, with the main one being household income. A study in South Africa showed that household income and electricity price are the main determinants of electricity demand [51]. Household size and dwelling type are also important determinants of electricity consumption [52]. For gaining access to electricity, household location is important. Access to electricity for a rural household has a more significant positive effect on education and health attainments than is the case for an urban household [53]. It is expected that electricity demand in rural areas is mainly for the purpose of lighting, with lighting also shown to affect children's education in developing countries. Grid electrification is not possible in rural areas due to budget constraints. Kanagawa and Nakata [54] reported that access to electricity was linked to infrastructure, supply capacity, government policy, and international cooperation.

Adoption of electricity at the household level depends on various socio-economic characteristics of the household, its geographical position, government policy, etc. Identifying the determinants of access to electricity at the household level is at times difficult due to a mix of individual characteristics and geographical factors. Khandker et al. [33] showed that, in Bangladesh, the impact of access to grid electrification on income and educational outcomes is positive and significant. In their study, they applied PSM and the instrumental variable (IV) approach to estimate the causal effect of access to electricity on income, expenditure, and educational outcomes. Their set of covariates included: gender, age, and level of education of head of household; household landholding, dwelling, and drinking water; village price of kerosene, etc. to estimate the propensity score of household access to electricity.

In another study, Khandker et al. [55] showed that, in Vietnam, the impact of access to grid electrification had significant positive effects on a household's cash income, expenditure, and educational outcomes. They applied difference-in-difference (DID), DID with fixed effect (FE) regression, and PSM–DID to estimate the causal effect of electrification. In their study, the propensity score of access to grid electricity was estimated based on: gender, age, and education level of head of household; household landholding and running water; commune price of kerosene, etc.

Kumar and Rauniyar [56] applied PSM to show the impact of access to electricity on income and educational outcomes in Bhutan, finding that it had a positive impact on non-farm income and educational outcomes. To estimate the propensity score, they used: household size; gender and age of head of household; amount of household land; access to tap water; house structure; religion; and distance as covariates.

The current study chose age, gender, and education level of head of household; family size; number of sleeping rooms; location, and having a water pump; and the wealth score from the

MICS database as covariates. The data did not include any income or expenditure information, and the wealth score was used as a proxy for the income variable.

2.2.3 Markov Model of Schooling Transition

The Markov schooling transition probability matrix was used to show the impact of access to electricity on school enrollment, measured by factors such as grade progression, grade repetition, and non-attendance. This transition matrix provides a convenient framework that can be used to assess the impact on various dimensions.

In Bangladesh, three possible schooling states are available for 5 to 6-year-old children: non-attendance, enrolled in grade 1, or enrolled in grade 2. In Bangladesh, most 6-year-old children are enrolled in grade 1. For 7-year-old children, four possible schooling states exist: enrolled in grade 3, enrolled in grade 2, enrolled in grade 1, and non-attendance. The most common state for 7-year-old children is enrolled in grade 2.

A transition probability matrix describes the transition using various ages for children by their schooling state. The distribution of 7-year-old children's schooling state, given the initial distribution of 6-year-olds, is obtained in the following way:

$$\begin{pmatrix} f_3^7 \\ f_2^7 \\ f_1^7 \\ f_{NA}^7 \end{pmatrix}_{4\times 1} = \begin{pmatrix} A_{11}^6 & A_{12}^6 & A_{13}^6 \\ A_{21}^6 & A_{22}^6 & A_{23}^6 \\ A_{31}^6 & A_{32}^6 & A_{33}^6 \\ A_{41}^6 & A_{42}^6 & A_{43}^6 \end{pmatrix}_{4\times 3} \begin{pmatrix} f_2^6 \\ f_1^6 \\ f_{NA}^6 \end{pmatrix}_{3\times 1}$$

The above matrix can be written in the following equation:

$$f^7 = A^6 f^6 \tag{6}$$

where A^6 is the transition matrix for children aged 6 years old, and f^6 is the vector of schooling state proportions. The study needed to increase the number of rows in the A matrix with age as the number of potential grade levels increases.

2.2.4 Estimating Short-Run Impacts: 1-Year Impacts

The current study had grading information for more than 30,000 children from electrified regions and more than 26,000 children from unelectrified regions. The nearest neighbor matching (NNM)-based PSM matched the data between the two types of region. Grade information was obtained for 26,499 children for both the treatment and control groups. It was considered that the 1-year impact of access to electricity for children of a given age a could be evaluated by comparing the age-specific transition matrix estimated for the treated (unelectrified) and control (electrified) groups:

$$\hat{A}^{a}_{T=1} - \hat{A}^{a}_{T=0}$$

Transition matrices were constructed for both groups which compared the short-run effects of access to electricity on grade progression, grade repetition, and non-attendance at each age, and taking the difference to estimate the impact of access to electricity. Matching ensured that the effect of access to electricity could be calculated by simply taking the difference between the two groups.

The study also tested whether the observed treatment and control group differences were statistically significant based on Pearson's chi-squared tests. Two types of tests were examined: an equivalence test between the treatment and control transition matrices, and a test of equivalence between the individual columns of the matrices.

2.2.5 Simulating Long-Run Impact of Access to Electricity

The long-run impact of access to electricity on school enrollment was of greater interest in the current study for policy purposes. Children in the data set were observed for only two years, therefore, the long-run impact of access to electricity could not be directly estimated. Therefore, a simulation approach was applied that used the Markov schooling transition model to predict the effects of access to electricity on school enrollment at age 15. The study made the following two assumptions about the greater validity of the evaluation process:

Assumption 1: *The number of children at age 4 is the same as the number expected to go to school at age 5.*

Assumption 2: *The age-specific transition matrices are consistent over time*.

Under both assumptions and given an initial vector of the state proportion at each age, the predicted schooling state could be found by the product of the previous age enrollment status and the state proportions of the current age. The mathematical expression for the predicted school enrollment status of 6-year-old children for both treatment and control groups is as follows:

$$\tilde{f}_g^6 = \hat{f}_g^5 \, \hat{A}^6$$

where the predicted enrollment status is indicated with a tilde (~) and things directly estimated from the age transition matrices are indicated with a hat (^). More generally, the predicted grade status at any age a is given by:

$$\hat{f}_g^a = \hat{f}_g^{a-1} \, \hat{A}^a$$

The study started with children at age 5 and completed the transition at age 15. At the end of the transition at age 15, various grade levels and non-attendance information were obtained for both treatment and control groups, with the difference then taken to judge the long-run impacts of access to electricity.

2.3 Description of the Data

The data are from Bangladesh's MICS database 2012–2013 created by the Bangladesh Bureau of Statistics (BBS), the Ministry of Planning, Bangladesh, and the United Nations Children's Fund (UNICEF). The survey collected comprehensive, detailed information on a wide range of topics, including: household information; household characteristics; education; water and sanitation; children under 5; women; salt iodization; and water quality testing. The data provide estimates at the national level with disaggregated data by division, location, gender, age, education level, and wealth quintiles. Bangladesh's MICS database 2012–2013 is based on a sample of 51,895 interviewed households and offers a comprehensive picture of children's education and nutrition. These panel data over two years captured information about children's school attendance and grades. From the data set, most 5- and 6-year-olds were enrolled in grade 1 or one of the three possible schooling states as follows:

- Non-attendance

- Enrolled in grade 1 or
- Enrolled in grade 2.

For children aged 7 years, four possible schooling states were available: enrolled in grade 3, enrolled in grade 2, enrolled in grade 1, and non-attendance. The definitions of the variables are given in Table 2.1.

Table 2.1: Variable definitions

Variable	Definition
Grade progression	Promotion from existing grade to upper grade
Grade repetition	Kept in the same grade due to bad performance
Non-attendance	Discontinue study due to various reasons
Access to electricity	Household has access to electricity or not (yes/no)
Gender of the head of household	Male/female
Age of head of household	Age in years
Family size	Average size of household by number of residents
Sleeping rooms	Number of sleeping rooms of household
Location	Household location (rural/urban)
Education level of head of household	Measured by years of schooling
Have a water pump	Household has a water pump or not (yes/no)
Wealth score	Composite index which ranges from 1 to 5

School enrollment (grade progression, grade repetition, and non-attendance) was considered as the outcome variable and access to electricity as the treatment. Some demographic and socio-economic features of the household were also considered as control variables.

2.4 Empirical Results and Discussion

2.4.1 Estimated Propensity Score of Access to Electricity

The current study sought to estimate the probability that a household would have access to electricity based on the observed values of characteristics (explanatory variables) such as gender, age, and education level of the head of household; location; family size; number of sleeping rooms; having a water pump; and the wealth score. As shown in Table 2.2, the likelihood that a household has access to electricity is smaller if the household family size is large, or if the household has a water pump or is headed by a male.

Table 2.2: Probit regression: estimated propensity score based on baseline observed characteristics

Dependent Variable: Access to Electricity Access to electricity = 1	**Full Set of Explanatory Variables**	**Limited Set of Explanatory Variables**
Explanatory variables: Baseline observed characteristics	Coefficient	Coefficient
Urban = 1	0.396 ***	
	(0.0227)	
Family_size	−0.0352 ***	
	(0.00388)	
Sleeping_rooms (number)	0.00729 **	
	(0.00135)	
Water_pump	−0.399 ***	
	(0.0636)	
Wscore (wealth)	1.869 ***	
	(0.0242)	
Head of household age	0.000665	
	(0.000445)	
Head of household gender (male = 1)	−0.0556 **	−0.212 ***
	(0.0221)	(0.0211)
Head of household's education level (years)	0.0115 ***	0.0947 ***
	(0.00194)	(0.00142)
Constant	0.559 ***	−0.0658 ***
	(0.0255)	(0.0209)
Observations	56,071	56,071

Note: Standard errors (SEs) in parentheses; *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

In contrast, living in an urban area, having more sleeping rooms, having a larger wealth score, and having a more educated head of the household all increase the likelihood that a household has access to electricity.

2.4.2 Estimated Average Treatment Effect on the Treated

The average treatment effect on the treated (ATET) always produces an identical outcome. The study applied the ATET to estimate the impact of electrification on school enrollment (grade progression, grade repetition, and non-attendance) through the NNM method (see Table 2.3).

Table 2.3: Average treatment effect on the treated (ATET)

Outcomes	(1) **Grade Progression**	(2) **Grade Repetition**	(3) **Non-Attendance**
ATET			
Access to electricity (1 vs. 0)	0.0276 ***	−0.00190	−0.0257 ***
	(0.00592)	(0.00177)	(0.00577)
Observations	56,071	56,071	56,071

Note: Standard errors (SEs) in parentheses: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

- Access to electricity increases grade progression by an average of 0.0276 (2.76%) which is statistically significant.
- Access to electricity has a negative impact on grade repetition and is statistically insignificant.
- Access to electricity decreases non-attendance by an average of 0.0257 (2.57%) and is statistically significant.

2.4.2.1 Impact Estimates (Short-Run and Long-Run) Based on Markov's Schooling Transition Model

Through Markov's schooling transition model, the study shows how access to electricity affects school enrollment. Firstly, the short-run impact of access to electricity on school enrollment was estimated by comparing the treatment and control group children. Secondly, the long-run impact of access to electricity was simulated using the method proposed in Section 2.4.

2.4.2.1.1 Comparison of Treatment and Control Groups (Short-Run)

Tables 2.4–2.6 provide the details of grade transition based on age, with other tables located in the Appendix. These tables show the estimates for the schooling transition matrices for children aged 5–15 years. Table 2.4 shows the distributed estimated probabilities of transitioning from three potential states at age 5 to four potential schooling states at age 6. The letter 'G' indicates the source state that corresponds either to grade promotion, to the same grade, or to non-attendance. The top panel of the matrices provides the transition matrix for the treated group (unelectrified), the middle panel provides the transition matrix for the control group (electrified), and the last panel shows the treatment–control group differences. Matching would imply that the differences between treatment and control groups due to electrification are largely supported by the data.

Impacts on primary school age children: From ages 5–6, the grade repetition rate is approximately 8% lower for those who have access to electricity compared to those who do not, as shown in Table 2.4. The transition from grade 1 to grade 2 is 8% more likely for those who have access to electricity compared to those who do not.

From ages 6–7, as shown in Table 2.5, the grade repetition rate is approximately 3.4% lower for those who have access to electricity than for those who do not. The transition from grade 1 to grade 2 is 3.4% more likely for those who have access to electricity compared to those who do not. In addition, the non-attendance rate is 10.4% lower for those who have access to electricity compared to those who do not. Thus, access to electricity appears to foster grade progression and reduce grade repetition. Furthermore, it reduces non-attendance among children which is a significant difference between the treatment and control samples.

Impacts on the transition to secondary school: From ages 12–13**,** the grade repetition rate is approximately 1.33% higher for those who have access to electricity compared to those who do not. Transitioning from grade 6 to grade 7 is 1.33% more likely for those who have access to electricity compared to those who do not. In addition, the non-attendance rate is 1.56% lower for those who have access to electricity compared to those who do not. These results are shown in Table 2.6.

Table 2.4: Transition matrices (age 5 to 6)

	Grade (G)		
	2	**1**	**NA**
		Treatment Transition Matrix	
P(3|G)	0.875	---	---
P(2|G)	0.125	0.564	---
P(1|G)	---	0.436	0.163
P(NA|NA)	---	---	0.837
Observation	8	181	2483
P(G)	0.003	0.068	0.929
		Control Transition Matrix	
P(3|G)	0.833	---	---
P(2|G)	0.167	0.645	---
P(1|G)	---	0.355	0.207
P(NA|NA)	---	---	0.793
Observation	12	211	2495
P(G)	0.004	0.078	0.918
		Treatment–Control Differences	
P(3|G)	0.042	---	---
P(2|G)	−0.042	−0.08	---
P(1|G)	---	0.08	−0.044
P(NA|NA)	---	---	0.044
Observation	20	392	4978
P(G)	0.004	0.073	0.924
p-value	0.76	0.08	0.25

Note: NA = non-attendance.

Table 2.5: Transition matrices (age 6 to 7)

		Grade (G)		
	3	**2**	**1**	**NA**
		Treatment Transition Matrix		
P(4|G)	1.000	---	---	---
P(3|G)	---	0.969	---	---
P(2|G)	---	0.031	0.797	---
P(1|G)	---	---	0.203	0.378
P(NA|NA)	---	---	---	0.622
Observation	16	96	693	2166
P(G)	0.005	0.032	0.233	0.729
		Control Transition Matrix		
P(4|G)	1.000	---	---	---
P(3|G)	---	0.960	---	---
P(2|G)	---	0.040	0.830	---
P(1|G)	---	---	0.170	0.482
P(NA|NA)	---	---	---	0.518
Observation	8	100	690	1899
P(G)	0.003	0.037	0.256	0.704
		Treatment–Control Differences		
P(4|G)	0.000	---	---	---
P(3|G)	---	0.009	---	---
P(2|G)	---	−0.009	−0.034	---
P(1|G)	---	---	0.034	−0.104
P(NA|NA)	---	---	---	0.104
Observation	24	196	1383	4065
P(G)	0.004	0.035	0.244	0.717
p-value	0.060	1.000	0.050	0.008

Note: NA = non-attendance.

Table 2.6: Transition matrices (age 12 to 13)

	Grade (G)									
	9	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**NA**
					Treatment Transition Matrix					
P(10|G)	1.000	---	---	---	---	---	---	---	---	---
P(9|G)	---	1.000	---	---	---	---	---	---	---	---
P(8|G)	---	---	0.995	---	---	---	---	---	---	---
P(7|G)	---	---	0.005	0.9822	---	---	---	---	---	---
P(6|G)	---	---	---	0.004	0.973	---	---	---	---	---
P(5|G)	---	---	---	---	0.027	0.997	---	---	---	---
P(4|G)	---	---	---	---	---	0.003	0.983	---	---	---
P(3|G)	---	---	---	---	---	---	0.017	0.986	---	---
P(2|G)	---	---	---	---	---	---	---	0.014	0.922	---
P(1|G)	---	---	---	---	---	---	---	---	0.078	0.011
P(NA|NA)	---	---	---	---	---	---	---	---	---	0.989
Observation	10	51	208	445	368	312	232	138	51	562
P(G)	0.0042	0.0215	0.0875	0.1872	0.1548	0.1313	0.0976	0.0581	0.0215	0.2364
					Control Transition Matrix					
P(10|G)	0.9091	---	---	---	---	---	---	---	---	---
P(9|G)	0.0909	0.9911	---	---	---	---	---	---	---	----
P(8|G)	---	0.0089	0.9906	---	---	---	---	---	---	---
P(7|G)	---	---	0.0094	0.996	---	---	---	---	---	---
P(6|G)	---	---	---	0.0178	0.9900	---	---	---	---	---
P(5|G)	---	---	---	---	0.0100	0.9861	---	---	---	---
P(4|G)	---	---	---	---	---	0.0139	0.9744	---	---	---
P(3|G)	---	---	---	---	---	---	0.0256	0.9804	---	---
P(2|G)	---	---	---	---	---	---	---	0.0196	0.9259	---
P(1|G)	---	---	---	---	---	---	---	---	0.0741	0.0262
P(NA|NA)	---	---	---	---	---	---	---	---	---	0.9738
Observation	11	112	320	618	399	360	195	102	27	305
P(G)	0.0045	0.0457	0.1307	0.2523	0.1629	0.1470	0.0796	0.0416	0.0110	0.1245
					Treatment–Control Differences					
P(10|G)	0.0909	---	---	---	---	---	---	---	---	---
P(9|G)	−0.0909	0.0089	---	---	---	---	---	---	---	---
P(8|G)	---	−0.0089	0.0046	---	---	---	---	---	---	---
P(7|G)	---	---	−0.0046	−0.0133	---	---	---	---	---	---
P(6|G)	---	---	---	−0.0133	−0.0171	---	---	---	---	---
P(5|G)	---	---	---	---	0.0171	0.0107	---	---	---	---
P(4|G)	---	---	---	---	---	−0.0107	0.0084	---	---	---
P(3|G)	---	---	---	---	---	---	−0.0084	0.0051	---	---
P(2|G)	---	---	---	---	---	---	---	−0.0051	−0.0044	---
P(1|G)	---	---	---	---	---	---	---	---	0.0044	−0.0156
P(NA|NA)	---	---	---	---	---	---	---	---	---	0.0156
Observation	21	163	528	1063	767	672	427	240	78	867
P(G)	0.0044	0.0338	0.1094	0.2203	0.1589	0.1392	0.0885	0.0497	0.0162	0.1797
p-value	0.85	0.72	0.31	0.06	0.46	0.25	0.40	0.87	0.13	0.04

Note: NA = non-attendance.

2.4.2.1.2 Long-Run Impacts of Access to Electricity and Comparison of Treatment and Control Groups

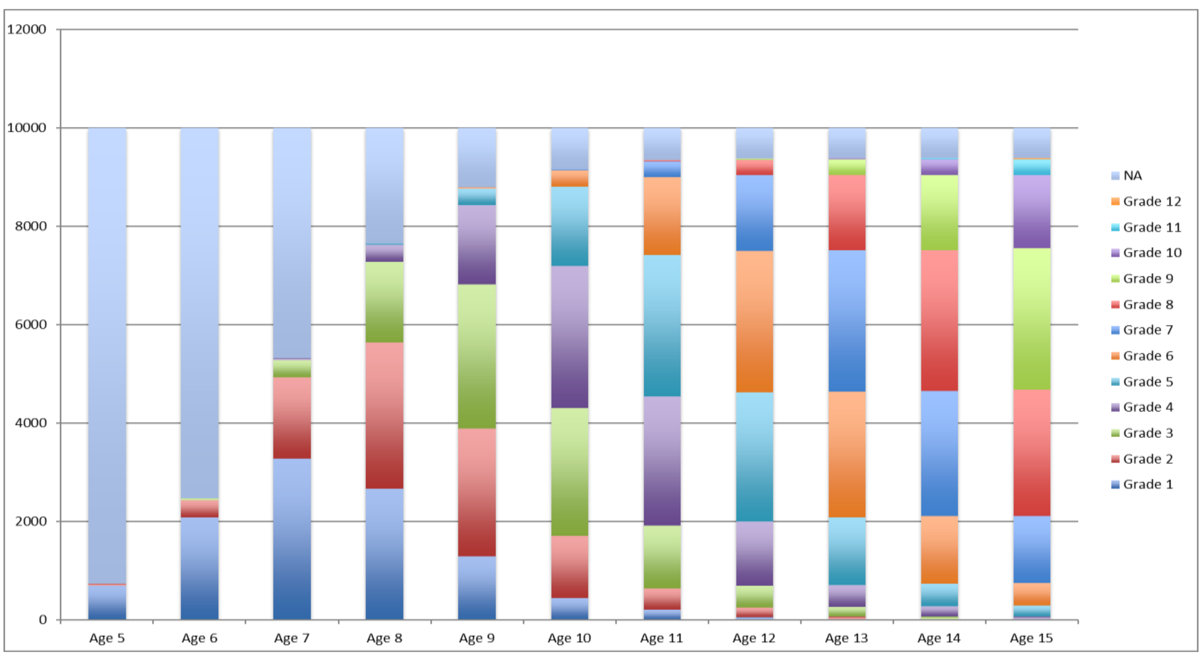
From the above results, the short-run impacts of access to electricity on school enrollment both for primary and secondary school children can be determined. These impacts have been shown year by year. The study's next goal was to connect the impact of access to electricity with school enrollment over a long period. In the short run, access to electricity has a significant positive impact on grade progression/transition, a significant negative effect on non-attendance, and mixed effects on grade repetition. The study was interested in determining the impact of access to electricity on school enrollment up to age 15, with year-by-year impacts expected to accumulate.

It was assumed that children had continuous access to electricity starting at age 5 and up to age 15. Transition matrices were then obtained from age 5 to age 15. It was supposed that 10,000 children of age 4 were expected to attend school at age 5 as shown in Table 2.7 (based on the transition matrix):

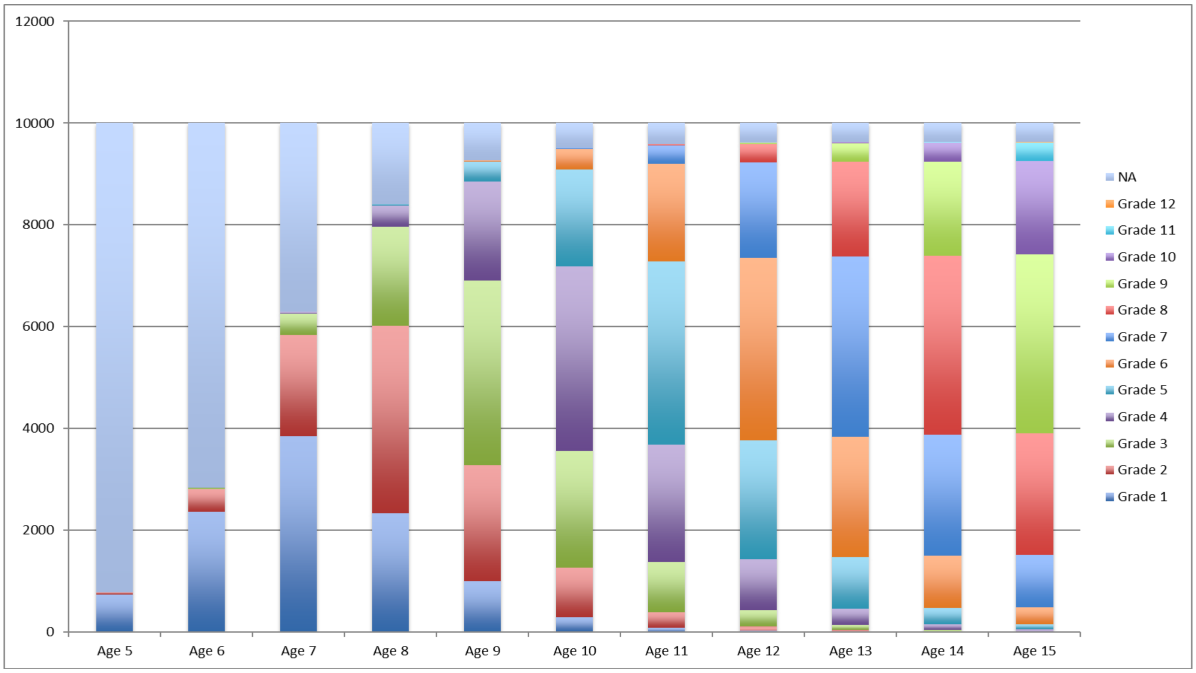
Table 2.7: Grade distribution at age 5

Categories	Grade 1	Grade 2	Non-Attendance
Treatment (Unelectrified)	690	43	9267
Control (Electrified)	733	40	9227

When the transition was examined up to age 15, the following results were obtained (see Figure 2.1):



Treatment (Unelectrified)



Control (Electrified)

Figure 2.1: Grade transition (age 5 to 15)

Consider a 15-year-old who enrolled in grade 1 at age 5 and will potentially reach grade 12 when he/she is age 15. He/she needs to complete 12 years of school to reach grade 12. This suggests that the treatment can be examined over 10 years based on access to electricity. The impact is summarized in Table 2.8 below:

Table 2.8: Long-run impact of access to electricity

Transition	Treatment (Unelectrified)	Control (Electrified)
Non-attendance	6.17%	3.69%
Grade 11	3.14%	3.57%
Grade 10	14.89%	18.40%
Grade 9	28.73%	35.15%

To estimate the long-run impact of access to electricity, a simulation was applied. The simulation assumed that a child is going to school continuously for 10 years, starting at age 5. The study compared the predicted school enrollment distribution between the unelectrified (treatment) and electrified (control) groups at age 15 and omitted non-attendance students. Table 2.9 presents the simulated probability distribution function (PDF) and cumulative distribution function (CDF) values for the treatment and control groups, with treatment defined as lacking access to household electricity for 10 years for the age range 5–15.

Table 2.9: Simulated school enrollment distribution at age 15 (treatment and control)

Grade	Treatment (PDF)	Control (PDF)	Treatment (CDF)	Control (CDF)
1	0.01	0.02	0.01	0.02
2	0.01	0.03	0.02	0.05
3	0.13	0.12	0.15	0.17
4	0.59	0.37	0.74	0.54
5	2.36	1.12	3.1	1.66
6	4.89	3.45	7.9	5.11
7	14.44	10.59	22.34	15.7
8	27.46	24.78	49.8	40.48
9	30.62	36.50	80.42	76.98
10	15.87	19.10	96.29	96.08
11	3.35	3.71	99.64	99.79
12	0.27	0.21	100	100

Figure 2.2 displays the school enrollment scenario for a 15-year-old child who has continuously attended school for the last 10 years. The school enrollment rate is higher for grades 9–11 in the electrified group compared to the unelectrified group, revealing substantial differences between the treatment and control groups. Most of the treatment impact occurs at age 14.

The study predicted the long-run impact of access to electricity on education, demonstrating that this is a very strategic policy option that justifies the provision of electricity in unelectrified regions to reduce school non-attendance. It was also noted that grade progression is affected by the quality of lighting which, especially in rural areas, is an important indicator on which education policy should focus. The quality of lighting provides an opportunity for students to study at night; it is the researcher's belief that it can increase school enrollment.

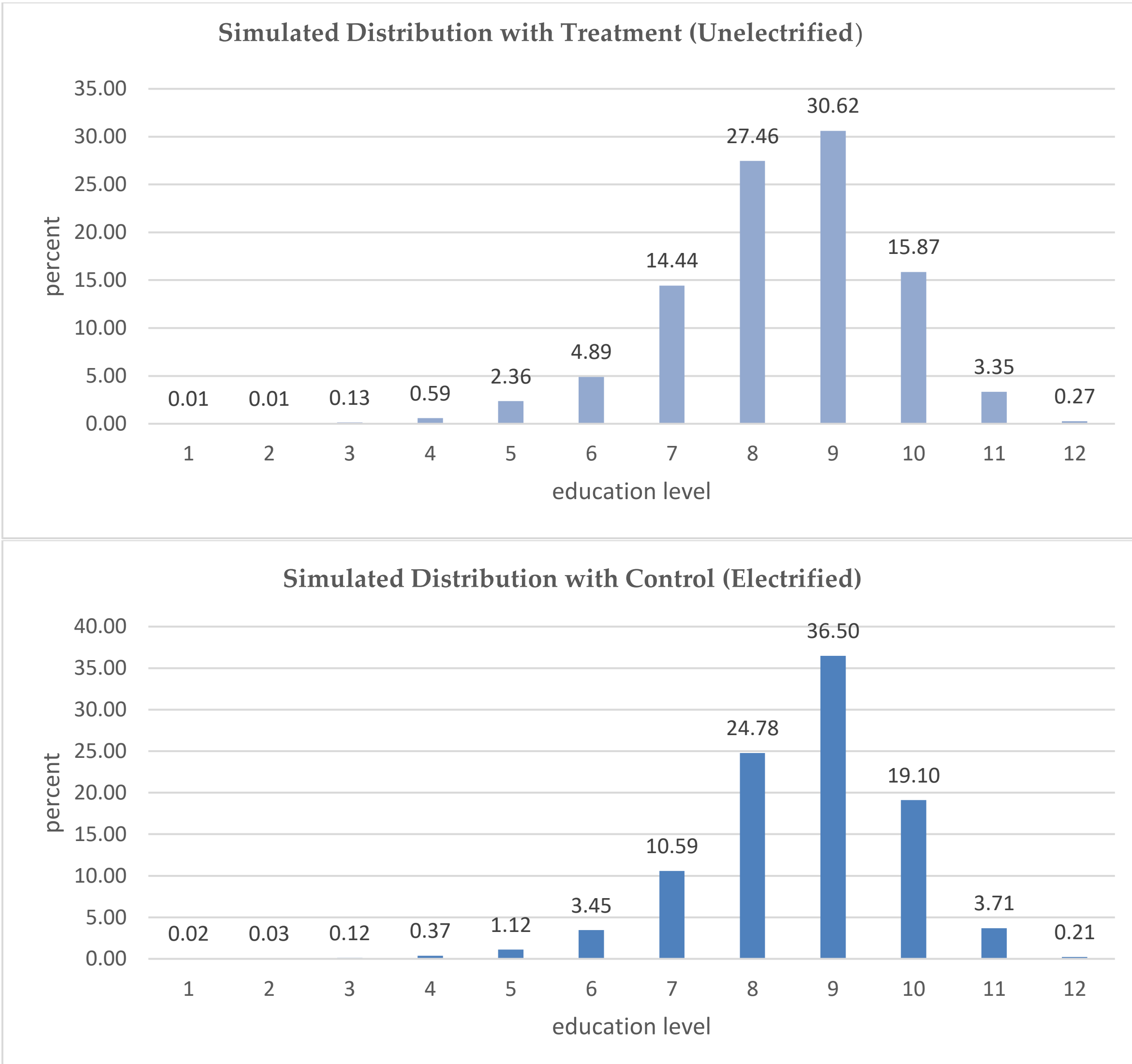


Figure 2.2: Simulated effects of treatment on school enrollment distribution at age 15

2.5 Conclusion

In theory, the impact of access to electricity on education is unclear, with multiple mechanisms possibly at work. No consensus was found in the empirical literature on the impact of access to electricity on education. This thesis documents empirical research that has tested the strategic policy question of whether access to electricity increases grade progression and reduces non-attendance rates for children aged between 5 and 15. The relationship between access to electricity and school enrollment is complex. Although access to electricity affects children's study, it is not the only factor (factors such as income, location, culture, and government policy are also considered very important). The occurrence of non-attendance results from the complex interaction of economic, individual, family, and school-related factors [57]. A positive relationship has been found between access to electricity and the household's economic condition [58]. The current study's focus point was to assess the impact of electrification on school enrollment. What was particularly notable in the current study was the impact of access to electricity on grade progression and non-attendance, observed between the treatment and control groups in both the short run and long run. Firstly, the average treatment effect on the treated (ATET) showed that access to electricity significantly increased grade progression and reduced non-attendance. Secondly, the Markov schooling transition model showed that access to electricity had a positive impact on grade progression and a negative impact on non-attendance in the short and long run. For grade repetition, however, access to electricity had a mixed effect.

Although some researchers found positive effects, others found no effect. In some instances, access to electricity showed some improvement in the number of study hours and level of school enrollment [59][60]. However, in another case, lighting had an insignificant effect on children's study time [61]. To contribute to the existing literature, the current study evaluated the impact of access to electricity on grade progression, grade repetition, and non-attendance. Overall, it was apparent that a broad scope exists for enhancing school enrollment by ensuring access to electricity. Education policies are needed to encourage school enrollment and to reduce non-attendance at primary and secondary schools based on strategic factors. These policies could provide financial support and better quality lighting, potentially increasing study continuation for children. It is noteworthy that the government of Bangladesh could take the initiative to reduce student non-attendance, which is partially caused by non-access to electricity. One empirical study showed that access to electricity reduces school attendance [62]. The current study's findings did not support this finding. However, improving the quality of lighting could be regarded as a way to reduce school non-attendance in Bangladesh. Many characteristics of rural areas make it more challenging (unfeasible and impractical) to provide grid electricity [63]. Improved targeting of educational research and resources on access to lighting and education might be a strong tool for maximizing school enrollment in Bangladesh.

Chapter 3: Impact of a Solar Home System (SHS) on Educational Outcomes in Rural Bangladesh

3.1 Introduction

Lack of adequate lighting severely undermines children's ability to learn at school and at home in rural areas [64]. Sustainable development is a common agenda for all countries, and renewable energy is the most crucial factor for achieving sustainable development through poverty reduction, energy security, and enhancing socio-economic and human development [65]. Solar energy is being given more importance in most developing countries, with their increasing populations and depleting fossil fuel resources [66]. More than two billion people do not have access to reliable energy in developing countries [67]. The range of activities for which SHS lighting has especially been found to be useful includes studying, reading, preparing food, taking care of children, processing agricultural products, and social interaction [68]. With the demographic composition of developing countries, the population under the age of 15 accounts for about 40% of the total population, so the calculated result would reach a total of 800 million people. As not all children go to school, the actual number of children studying at night would be less than this figure of 800 million. However, more than 500 million children lack adequate lighting and use dim, smoky and dangerous kerosene lighting while studying at night [69]. As the SHS is considered to be a reliable and clean source of lighting in rural areas of developing countries, the current study sought to examine the impact of the SHS on educational outcomes.

Energy poverty is a big problem for developing countries, and is regarded as a multidimensional problem. Multidimensional policies are therefore needed to solve the problem, thus ensuring productive uses of energy [70]. Electrification in rural areas in developing countries through renewable energy is a good way to expand the implementation of electricity technology. However, the policy should target the fostering of human capital accumulation by ensuring local people's participation in planning and implementation processes [10]. Political and academic discourses often assume that access to energy will lead to benefits for development. Although this is true to a certain extent, education, livelihoods, and the health benefits of access to energy do not directly manifest themselves. The use of electricity is interrelated with multiple aspects of socio-economic development through complex causal relationships, such as income-generating activities, market production and revenue, the household economy, local health and population, education, habits, and social networks [71]. In addition, lighting from electricity reduces indoor air pollution and the health hazards caused by kerosene lamps [72].

An SHS not only fulfills the household's lighting demand but it also contributes to income generation for small business enterprises [73]. One study has critically evaluated the success story of the SHS program based on milestones such as energy access and uses, social impact, economic impact, management and ownership of the program, environmental impact, and impact on gender [15]. A household with an SHS can work at night to generate additional income [74]. Owners of SHSs reported that their quality of life increased and that more job opportunities were created [75]. Moreover, they enjoyed watching television, recharged their mobile phones at home, and reduced their kerosene consumption expenditure [76]. Based on an evaluation of six case studies, solar electrification was found to create green employment opportunities. It also reduced kerosene subsidies. That is, the SHS was considered as friendly to the rural environment and eco-efficient [77]. One field survey assessment in Assam, India, evaluated the technical performance of SHSs, service delivery, institutional arrangements, user satisfaction, and benefits for rural livelihoods [78].

The current study contributes to strengthening the evidence of the impact of solar lighting on children's education in rural areas in low-income countries. Many methods are useful in improving children's educational performance. However, many educational economists have questioned the effectiveness of these methods over the past decade, whether in developing or developed countries. Some recent studies have argued that providing higher incentives is usually more effective than providing a better learning environment to improve children's educational outcomes. Interventions such as merit scholarships, school health programs, and information about educational returns can cost-effectively stimulate school participation [79]. A randomized evaluation has shown that providing textbooks improved the performance of the best students, but this had little impact on other students [80]. McEwan [81] did not find evidence of improved educational scores with the provision of midday meals, using the regression discontinuity method. A school-based deworming program in Kenya increased the average participation in treatment schools by 7.5 percentage points, reducing overall school absenteeism by at least a quarter [82]. Most studies have examined financial support for children's educational performance. In a rural setting, access to electricity is the main barrier to socio-economic development of which electrification is an integral part. Therefore, it was decided in this study to examine the impact of the SHS on children's educational outcomes in rural Bangladesh. For the purpose of the study, access to the SHS was defined as access to light points (lamps).

Until now, the link between access to electricity and education has barely been analyzed. Most academic research has assumed that access to electricity has a beneficial effect on education. However, direct studies are lacking on the connection between access to electricity and children's educational outcomes. Some previous studies have focused on the impact of electrification on income, expenditure, and educational outcomes. Evidence from these studies has been used to provide greater justification for the current study. Kanagawa and Nakata [11] highlighted that, in the case of India, a positive correlation exists between per capita domestic electricity consumption and education level, indicating that households with very low initial electricity consumption can obtain high educational attainment by increasing electricity consumption. Electricity can also significantly improve the length of years at school and the learning time for children in rural households [33]. Home electrification has a positive effect on enrollment and the average years of schooling, but these facts are only statistically significant for girls [83]. Better lighting allows girls to redistribute their time to enable their schooling, but this is less so for boys as their job alternatives to school education are more likely to be at home engaged in income-generating activities. Children with access to electricity can do their homework in the evening after school, thus prompting their school attendance [29]. A few studies have been conducted to investigate the impact of solar energy on educational outcomes. Gustavsson [84] pointed out that children in families with access to solar energy spend more time doing homework than neighboring children who do not have access to solar energy. An SHS provides better quality light and reduces indoor air pollution that may also help to extend children's study hours [16].

A considerable amount of literature is already available on a different aspect of the SHS's influence on education (extended study hours for children). However, the literature on the causal inference of the SHS on educational outcomes (students' performance, grade progression, dropping out, grade repetition, and non-attendance) is seriously lacking. Most previous studies have examined the impact of the SHS on socio-economic activities by using descriptive statistics and qualitative analysis. Therefore, the current study sought to estimate the causal impact of the SHS on educational outcomes in rural Bangladesh.

3.2 Energy Scenario and Solar Home System (SHS) Prospects in Rural Bangladesh

Several sources of lighting are used in Bangladesh including grid electricity, kerosene, solar power, biogas, etc. Access to electricity is increasing due to expansion of the grid area, with 68% of the total population having access to grid electricity (including renewable energy) but, per capita, electricity generation is still low compared to the world average of 348 KWh [85]. In 1977, the Bangladesh government undertook a major initiative to expand electrification in rural areas under the Total Electrification Program and established the Rural Electrification Board (REB). According to the *Bangladesh Rural Electrification Board Act 2013*, the name of the Rural Electrification Board (REB) is now the Bangladesh Rural Electrification Board (also REB). The primary objective of REB is to extend electricity supply in rural areas to promote social and economic development. Its operational functions are organized in each area by the *Palli Bidyut Samity* (PBS) (i.e., the rural electric association or cooperative). The PBSs are semi-autonomous entities that the REB has approved and registered. Each PBS has adequate capacity in the grid substation and accessibility to the Bangladesh Power Development Board (BPDB)'s 33 kV line. The typical PBS covers 5-10 subdistricts with an area of 1,500–2,400 square kilometers and a consumer population of approximately 35,000–270,000 people. In Bangladesh, 78 PBSs are approved and registered with the REB and distribute electricity to over 69,000 villages through 767 substations. However, only about 30% of rural households have access to electricity from the grid [86]. Many rural area characteristics make it more challenging to provide these areas with electricity than is the case in urban areas [87][88]. Some villages still do not have electricity from the national grid. Due to the remoteness of these areas, electricity production, transmission, and distribution costs are relatively high.

The rural economy of Bangladesh is characterized by its high dependence on agriculture, inadequate energy, insufficient infrastructure, and widespread poverty. In Bangladesh, the non-exhaustive energy sources of solar, biomass, biogas, hydro, and wind, all of which are environmentally sustainable, can potentially be used to produce electricity in off-grid rural areas. Bangladesh has great potential for renewable energy development and is blessed with considerable solar radiation. Renewable energy can be seen as a potential solution for

Bangladesh's future energy needs and can provide electricity, especially in rural areas [89]. The Infrastructure Development Company Limited (IDCOL) is a government-owned financial institution that promotes private sector financing for infrastructure and renewable energy-based electricity in rural Bangladesh [90]. Its market size comprises four million SHSs on a fee-for-service basis in the off-grid areas in Bangladesh. About 18 million people, that is, 12% of the total population have access to the SHS in off-grid areas, with these people previously having used kerosene as a source of lighting. The government's vision is to provide electricity to all citizens by 2021 at a reasonable and affordable price. However, the fact is that grid power will not be available in some remote and isolated areas for the next 20 years. As a result, a very large number of people will live without electricity for a long time. The share of renewable energy to total electricity production was 3.5% in 2015 and the government's expectation is that it will be 10% before 2020 [91].

3.3 Study Area and Data Collection Methods

The study area for the current research is Rahumari *upzilla*, Kurigram district, Bangladesh. This area was purposively selected, based on the following three indicators: low access to electricity (18.7%), low literacy rate (34.6%), and low school attendance rate. Cross-sectional surveys were conducted as the primary method of data collection. The five *unions* in Rahumari *upzilla* are Dadbanga, Chor Showlmari, Bondebar, Rahumari, and Jadurchar. The study area chosen, based on purposive sampling, was the Chor Showlmari *union*. Information was gathered from the *Upzilla Nirbahi* Officer (UNO), the *Union* Chairman, and non-governmental organizations (NGO) for a greater understanding of the study area selected. The survey was conducted in nine villages between March 8, 2018 and April 15, 2018.

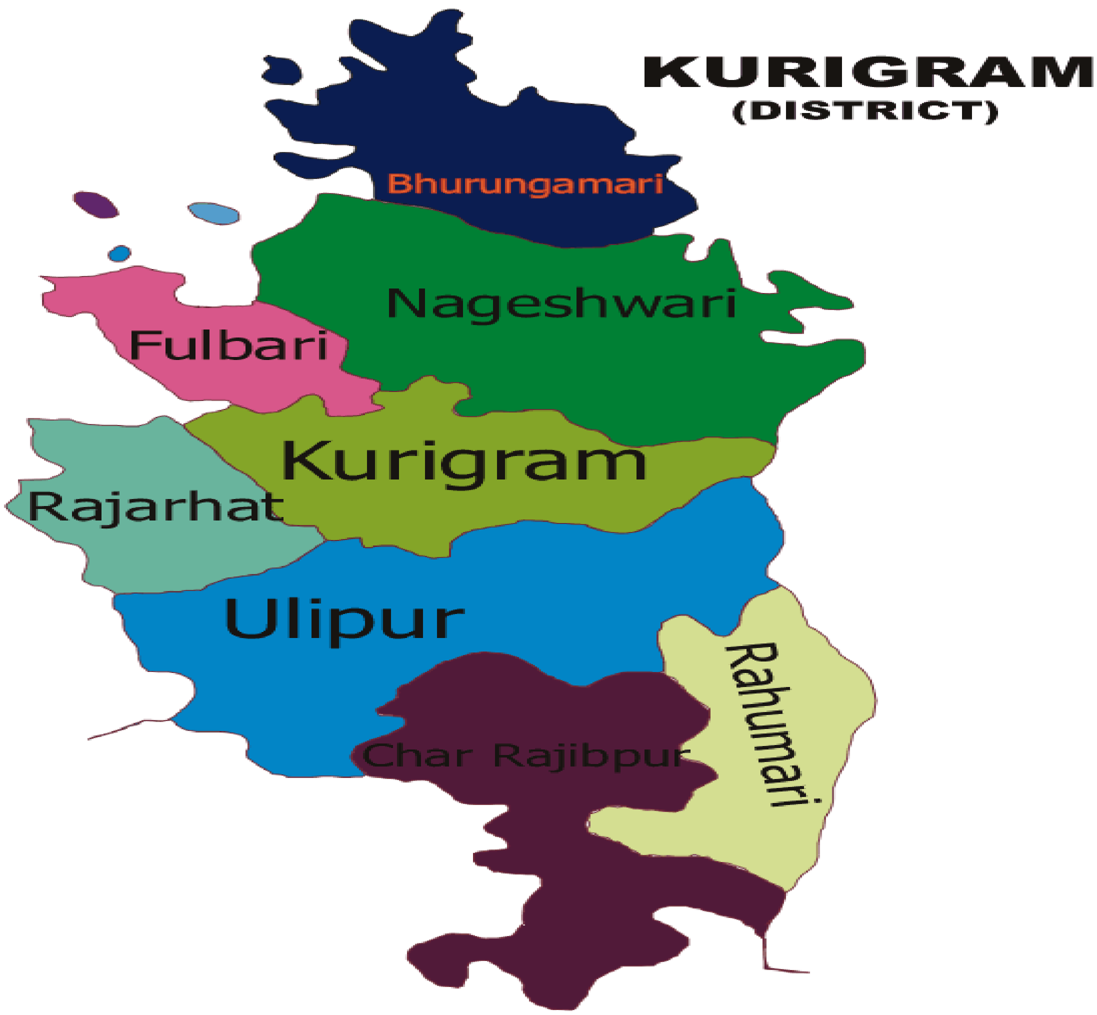


Figure 3.1: Map of Kurigram district

For the data collection, village-level cluster random sampling was employed. In total, 912 households and 1,696 children, ranging in age from 6–20 years with different grade information over three years, were surveyed. The paper-based questionnaire covered variables such as the household's socio-economic status, income generation, and children's education. The questionnaire was carefully designed and rigorously implemented to minimize questionnaire investigator bias and to prevent the investigator from leading the respondents. Despite these efforts, some responses may reflect the investigator's bias and need a more explicit framework for the issues raised.

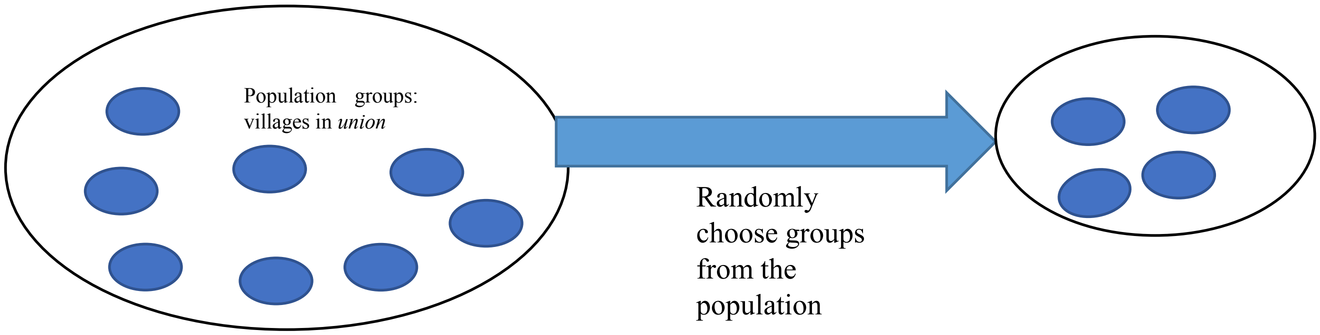


Figure 3.2: Village-level cluster sampling

Table 3.10: List of villages and target respondents

Name of Villages	Number of Households	Number of Children
Balugram	99	158
Batkemari	66	143
Char Showlmari	129	220
Chargenderalga	76	136
Gugumari	101	205
Miarchor	97	211
Pakhiura	196	340
Shukherbati	76	144
Sonapur	72	139
Total	912	1696

The aim of the questionnaire was to collect grading information related to the education of children in participating households through the issues of whether their household had, or did not have, a solar home system (SHS). These issues involved the socio-economic aspects of lifestyle and the impact of lighting on children's education in the selected villages. Specifically, this holistic research and the survey questions were designed to understand how indoor SHS lighting motivated a child to concentrate on their study and its effect on their household's living conditions.

Table 3.2: Status of household and children regarding SHS

	With SHS	Without SHS	Total
Household	356	556	912
Children	673	1023	1696

3.4 Matching Techniques

When using observational data for impact assessment, selection bias is the primary concern. This happens when a household with favorable characteristics, arising from their knowledge of the choices, adopts an SHS earlier than other households. Selection bias may exaggerate the measured value as early adopters may have received better facilities than late adopters, even without intervention. Selection bias is the main problem when observational data are used for impact assessment. It makes the estimation biased and exaggerates the measured impact. The current study could apply various treatment models to address selection bias in its investigation of the association between the SHS and educational outcomes. In this study, access to an SHS is the intervention. The study area is not electrified and has no possibility of electrification within the next 10 years. Solar home systems (SHSs) are the only reliable source of modern lighting for people in this disadvantaged region.

Selection bias occurs when a household that has information about the SHS, obtained due to their choices, adopts an SHS earlier than other households. The difference in the means of potential outcomes can be computed using both OLS regression and treatment models, depending on whether the household has an SHS (treatment) or not (control). The potential outcomes of these counterfactuals are defined as Y_0 if members of the sample do not have SHS and Y_1 if everyone in the sample has a solar home system (SHS). In the absence of unmeasurable confounding factors, the resulting regression model can be modeled as $(Y|T,X)$ where X refers to the observed variable, with the average of the two treatment estimates being $T = 1$ and the control being $T = 0$. Subsequently, the average treatment effect (ATE) in the population can be estimated as follows:

$$\triangle ATE = E(Y_1) - E(Y_0) \tag{7}$$

However, in traditional OLS analysis, ATE is approached by controlling a series of observed factors in a predictive model. The treatment coefficient effect is explained based on the control, as indicated by the causal effect on the dependent variable. However, problems arise when individuals with different background characteristics receive the treatment, leading to confounding and selection bias [92]. Treatment models attempt to overcome the problem of differentially selected treatments by including the predictive factors observed before the treatment or weighting the ATE level of the subject, including those associated with the treatment. This consists of analysis in two steps: estimating the "treatment model" (using observation factors to predict the treatment status of each subject), and then estimating the "predictive model" (using the same observations plus treatment variables to predict the outcome). Conversely, if the reverse is correct, the ATE can be correctly estimated if the model predicting the treatment outcome is correctly specified, while the treatment model is incorrect or incomplete [93][94][95]. In other words, if the propensity score model (balance treatment) is correct or the outcome model (predicted *Y*) is correct, the estimate of the average treatment for *X* is correct.

Causal estimation is identifiable if the three conditions of exchangeability, consistency, and positivity are all met. This means that the causal effect can be estimated as follows:

$$\check{T} = \frac{1}{n_T}\sum_{T_i=1} y_i - \frac{1}{n_C}\sum_{T_i=0} y_i$$

where n_T and n_C indicate the sample size in the treatment and control groups. This estimation is simply the difference between the average treated and control outcomes. In the case of confounding, the exchangeability hypothesis is wrong, which means that the above factors are not unbiased for the true population average causal effect. Methods are available to eliminate confounding and to estimate causal effects.

In theory, as empirical tests of causal claims have become more critical within the social sciences, researchers relying on observational data are faced with the lack of data sets to use in estimating causal effects. Unlike an experimental design, researchers cannot influence the distribution of the treatment, which can lead to biased results. Statistical matching provides a way to solve this problem by finding "statistical twins," one with and one without the treatment. However, the most common matching technique – propensity score matching (PSM) – is slow and difficult to apply. Coarsened exact matching (CEM) provides an alternative solution that is faster and easier to understand. It temporarily roughens the data based on the researcher's thoughts and then finds an exact match. The increased efficiency and lower bias properties of CEM are attributed to an exact match between the common strata defined by variance variables in the decision to participate or not participate in the program. Effectively, CEM allows a more comparable evaluation of the treatment group and comparison group by creating proportionality between the factors that contribute to the result concerned.

The current study's treatment and control groups are not necessarily identical as they lack random assignment of participants. Thus, the following steps are needed:

- ✓ The study denotes that all covariates are reasonably coarsened as much as possible.
- ✓ All coarse variables are placed in a single layer with the same units.
- ✓ Strata without at least one treated and one control unit are weighted zero (0).

The treatment effect for treated ($T_i = 1$) observation *i*:

$$T_i = Y_i(T_i = 1) - Y_i(T_i = 0)$$

$=$ Observed - Unobserved

- Estimate $Y_i(T_i = 0)$ with Y_j from matched $\left(X_i \approx X_j\right)$
- Prune unmatched units to improve balance
- Sample average treatment effect on the treated (SATT):

$$SATT = \frac{1}{n_T} \sum_{i \in \{T_i = 1\}} TE_i$$

3.5 Findings and Discussion

Table 3.3 presents the demographic and socio-economic characteristics of the households that had access to an SHS and those who did not.

Table 3.3: Covariate t-test statistics

Potential Covariates	With SHS		Without SHS			
	N	Mean	N	Mean	Std. error	Diff
HH Gender (dummy) [1=male, 0=female]	673	0.9270	1023	0.9424	0.01657	-0.0155
HH Age	673	44.1517	1023	41.8327	0.65494	2.319***
Religion1 (dummy) [1=Islam, 0 other]	673	0.9944	1023	0.9982	0.00389	-0.00382
Religion2 (dummy) [1=Hindu, 0 other]	673	0.0056	1023	0.0018	0.00389	0.00382
HH Education (years)	673	3.8848	1023	1.6047	0.26183	2.280***
HH Occupation1 (dummy) [1=Agriculture, 0 other]	673	0.5337	1023	0.6745	0.03266	-0.141***
HH Occupation2 (dummy) [1=Business, 0 other]	673	0.2865	1023	0.0773	0.02386	0.209***
HH Occupation3 (dummy) [1=Service, 0 other]	673	0.0590	1023	0.0144	0.01183	0.0446***
HH Occupation4 (dummy) [1=Day labour, 0 other]	673	0.0562	1023	0.1996	0.02335	- 0.143***
HH Occupation5 (dummy) [1=Other, 0 other]	673	0.0646	1023	0.0342	0.01421	0.0304*
HH Income (BDT per Year)	673	186132.0000	1023	79546.7600	22212.89000	106585.3***
Family Size	673	5.2219	1023	4.6191	0.10197	0.603***
No. of Immigrant Members	673	0.1461	1023	0.0144	0.02447	0.132***
No. of Sleeping Rooms	673	2.4607	1023	1.7518	0.05595	0.709***
Value of Non_Agri Asset (BDT)	673	40352.7200	1023	7541.3670	2578.64300	32811.4***
Distance from PBS (km)	673	69.7949	1023	68.9568	0.46641	0.838*
Distance from School (km)	673	0.9551	1023	1.0087	0.06123	-0.0536
Agri land (decimal)	673	156.9031	1023	44.4712	17.38146	112.4***
Toilet1 (dummy) [1=Water-sealed slab, 0 other]	673	0.1854	1023	0.0450	0.01983	0.140***
Toilet2 (dummy) [1=Not water-sealed slab, 0 other]	673	0.5169	1023	0.2662	0.03162	0.251***
Toilet3 (dummy) [1=*Katcha*, 0 other]	673	0.2949	1023	0.6691	0.03159	- 0.374***
Toilet4 (dummy) [1=Open space, 0 other]	673	0.0000	1023	0.0180	0.00705	- 0.0180*
Drinking Water 1 (dummy) [1=Tube well, 0 other]	673	1.0000	1023	0.9856	0.00632	0.0144*
Drinking Water 2 (dummy) [1=Pond, 0 other]	673	0.0000	1023	0.0018	0.00225	-0.0018
Drinking Water 3 (dummy) [1=River, 0 other]	673	0.0000	1023	0.0018	0.00225	-0.0018
Cooking Fuel1 (dummy) [1=wood, 0 other]	673	0.8789	1023	0.8561	0.02323	0.0228
Cooking Fuel 2 (dummy) [1=Cow dung, 0 other]	673	0.1014	1023	0.1439	0.02263	-0.0425

Cooking Fuel 3 (dummy) [1=LPG, 0 other]	673	0.0169	1023	0.0000	0.00547	0.0169**
Cooking Fuel 4 (dummy) [1=Biogas, 0 other]	673	0.0028	1023	0.0000	0.00225	0.0028

Notes: BDT=Bangladeshi taka (currency); HH=household head; *Katcha*=dwelling; LPG=liquefied petroleum gas; PBS=*Palli Bidyut Samity*; *level of significance 10%; **level of significance 5%; ***level of significance 1%

3.5.1 Results and Discussion Based on Coarsened Exact Matching (CEM) Method

The core motivation of the coarsened exact matching (CEM) method is to temporarily coarsen each observed variable into a meaningful group. These coarsened data are then matched exactly with only the original (un-coarsened) values of the matching data retained. The CEM process first coarsens the data to $C(X)$, then divides the observation into layers that result in cross-classification of the resulting results, and finally performs an exact match within each segment [96]. Therefore, the primary goal of any matching procedure is to maximize the two balances, namely, the similarity between the intervention and the observed multivariate distribution and the size of the matching data set. Statistical modeling assumptions must handle any remaining imbalance after matching.

The current study needed to select the model which ensured the covariate balance between the treatment and control models. Each matching method faces a fundamental problem: matching along the similarity measure does not necessarily achieve covariate balancing. Similarity measures may create a balance, but the results are usually not guaranteed. In practice, most matching methods require the researcher to adjust and re-run the matching program multiple times until a satisfactory balance is achieved. The current study created different models based on different combinations of covariates or slightly different covariates to ensure that the similarity between the treated and un-treated models was achieved. As shown in Table 3.4, 12 models were created based on covariate differences.

Table 11: Model specification

Covariates	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12
HH Gender (dummy) [1=male, 0=female]	√		√	√	√					√	√	
HH Age	√	√	√	√	√	√	√	√			√	√
Religion1 (dummy) [1=Islam, 0 other]												
Religion2 (dummy) [1=Hindu, 0 other]												
HH Education (years)	√	√	√	√	√	√	√	√	√	√	√	√
HH Occupation1 (dummy) [1=Agriculture, 0 other]	√						√				√	
HH Occupation2 (dummy) [1=Business, 0 other]			√			√		√				
HH Occupation3 (dummy) [1=Service, 0 other]												
HH Occupation4 (dummy) [1=Day labour, 0 other]												
HH Occupation5 (dummy) [1=Other, 0 other]												
HH Income (BDT per Year)	√			√				√	√	√		√
Family Size	√	√	√	√	√	√	√	√	√			√
No. of Immigrant Members	√	√	√	√	√	√	√	√	√	√	√	√
No. of Sleeping Rooms		√	√									
Value of Non_Agri Asset		√				√						
Distance from PBS (km)	√	√	√	√	√		√	√		√	√	
Distance from School(km)												
Agri land (decimal)	√											
Toilet1 (dummy) [1=Water-sealed slab, 0 other]										√		√
Toilet2 (dummy) [1=Not water-sealed slab, 0 other]					√	√			√			
Toilet3 (dummy) [1=Katcha, 0 other]	√		√				√	√			√	
Toilet4 (dummy) [1=Open space, 0 other]												
DrinkingWater1 (dummy) [1=Tube well, 0 other]					√							
Drinking Water2 (dummy) [1=Pond, 0 other]												
Drinking Water3 (dummy) [1=River, 0 other]												
Cooking Fuel1 (dummy) [1=wood, 0 other]		√										
Cooking Fuel 2 (dummy) [1=Cow dung, 0 other]												
Cooking Fuel 3 (dummy) [1=LPG, 0 other]												
Cooking Fuel 4 (dummy) [1=Biogas, 0 other]												

Notes: BDT=Bangladeshi taka (currency); HH=household head; *Katcha*=dwelling; LPG=liquefied petroleum gas; PBS=*Palli Bidyut Samity*

Coarsened exact matching (CEM) “coarsens” the data by binning along each covariate. Within each interval of the multivariate histogram, the control unit matches the processing unit. This method is shown as a “monotonic imbalanced boundary” as the maximum distance along any covariate between the treatment and control groups is controlled by a user-controlled (or default) value.

Table 3.5 presents the CEM Index for various models by the multivariate distance. The results here are from running 12 models based on different covariate combinations. For comparison purposes, the study estimated the multivariate distance before and after coarsened exact matching (CEM). The overall imbalance is given by the $\mathcal{L}_1$ statistic, as a comprehensive indicator of global imbalances [97]. It is based on the same L_1 difference between the multidimensional histogram of all pre-treatment covariates in the treatment group and in the control group. Firstly, the covariate is coarsened into boxes. To use this metric, a list of bin sizes for numeric variables is needed. The function within the current study automatically calculates these functions, or they can be set by the user. The discretized variables of the processing group and the control group are then cross-tabulated to $X_{1\times \dots\dots \times}X_k$ and record the k-dimensional relative frequency processed treated $f_{l1} \dots f_{lk}$ and control $g_{l1} \dots g_{lk}$ units. The value of the imbalance is calculated by the following equation:

$$\mathcal{L}_1\,(f, g) = \frac{1}{2} \sum_{l_{1\dots}l_k} | \, f_{l1} \dots f_{lk} - g_{l1} \dots g_{lk} \, |$$

The result indicates that $\mathcal{L}_1 = 0$, that is, perfect global balance and $\mathcal{L}_1 = 1$, that is, complete separation. If f^m and g^m are used to indicate the relative frequency of the matching data set, then a good matching solution will produce a reduction in the $\mathcal{L}_1$ statistic; that is, what the study wants is $\mathcal{L}_1(f^m, g^m) \leq \mathcal{L}_1(f, g)$.

Table 3.5: Coarsened Exact Matching (CEM) Index summary

CEM Index	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12
Multivariate L1 distance before CEM	0.9603	0.7773	0.8535	0.76134	0.6865	0.6924	0.7582	0.8660	0.5173	0.4919	0.6394	0.6383
Multivariate L1 distance after CEM	0.8482	0.5819	0.5928	0.45951	0.3764	0.3889	0.4391	0.5057	0.2366	0.2043	0.3020	0.3770
Number of Strata	605	311	452	364	299	252	364	471	103	99	223	285
Matched Strata	61	80	77	91	101	76	105	89	38	29	83	81
Matched Treated	139	356	233	342	408	399	360	249	480	474	439	366
Unmatched Treated	516	299	422	313	247	256	295	406	175	181	216	289
Matched Control	250	745	498	724	789	858	568	450	995	970	819	826
Unmatched Control	754	259	506	280	215	146	436	554	9	34	185	178
Total Treated	655	655	655	655	655	655	655	655	655	655	655	655
Total Control	1004	1004	1004	1004	1004	1004	1004	1004	1004	1004	1004	1004

Table 3.6: Results of sample average treatment effect on the treated (SATT) for Models 1, 2, and 3

OUTCOME VARIABLES	**Model 1**			**Model 2**			**Model 3**		
	n	**Coef.**	**SE**	**n**	**Coef.**	**SE**	**n**	**Coef.**	**SE**
GPA [Grade point average]	389	0.592**	0.19704	1101	0.578***	0.11464	731	0.750***	0.14489
Receiving scholarship	389	0.0589	0.04539	1101	0.126***	0.02543	731	0.127***	0.03147
Grade progression	389	0.0504	0.05076	1101	0.0594	0.03135	731	0.0655	0.03988
Grade repetition	389	-0.0285	0.03122	1101	-0.0322	0.02034	731	-0.0106	0.02466
Non-attendance	389	-0.00967	0.03955	1101	0.00166	0.02404	731	-0.0145	0.03104

Note: *Level of significance 10%; **level of significance 5%; ***level of significance 1%; Coef=coefficient; n=number; SE=standard error

Table 3.7: Results of sample average treatment effect on the treated (SATT) for Models 4, 5, and 6

OUTCOME VARIABLES	**Model 4**			**Model 5**			**Model 6**		
	n	**Coef.**	**SE**	**n**	**Coef.**	**SE**	**n**	**Coef.**	**SE**
GPA [Grade point average]	1066	0.554***	0.12532	1197	0.654***	0.1160	1,257	0.623***	0.1170
Receiving scholarship	1066	0.0990***	0.02556	1197	0.0914***	0.0245	1,257	0.105***	0.0284
Grade progression	1066	0.0549	0.03569	1197	0.0746*	0.0309	1,257	0.0584*	0.0313
Grade repetition	1066	-0.0364	0.02832	1197	-0.0132	0.0201	1,257	-0.00703	0.0191
Drop-out	1066	-0.0152	0.01176	1197	-0.0344**	0.0122	1,257	-0.0305*	0.0120
Non-attendance	1066	-0.00334	0.02428	1197	-0.027	0.0242	1,257	-0.0209	0.0246

Note: *Level of significance 10%; **level of significance 5%; ***level of significance 1%; Coef=coefficient; n=number; SE=standard error

Table 3.8: Results of sample average treatment effect on the treated (SATT) for Models 7, 8, and 9

OUTCOME VARIABLES	**Model 7**			**Model 8**			**Model 9**		
	n	**Coef.**	**SE**	**n**	**Coef.**	**SE**	**n**	**Coef.**	**SE**
GPA [Grade point average]	928	0.650***	0.12229	699	0.601***	0.15491	1,475	0.588***	0.1044
Receiving scholarship	928	0.0859**	0.02970	699	0.101**	0.03260	1,475	0.0769**	0.0246
Grade progression	928	0.0556	0.03163	699	0.0227	0.03971	1,475	0.0832**	0.0308
Grade repetition	928	-0.0126	0.02044	699	-0.0196	0.02691	1,475	-0.0345	0.0248
Drop-out	928	-0.0372*	0.01495	699	-0.00978	0.01220	1,475	-0.0292	0.0151
Non-attendance	928	-0.00591	0.02220	699	0.00666	0.03012	1,475	-0.0194	0.0188

Note: *Level of significance 10%; **level of significance 5%; ***level of significance 1%; Coef=coefficient; n=number; SE=standard error

Table 12: Results of sample average treatment effect on the treated (SATT) for Models 10, 11, and 12

OUTCOME VARIABLES	**Model 10**			**Model 11**			**Model 12**		
	n	**Coef.**	**SE**	**n**	**Coef.**	**SE**	**n**	**Coef.**	**SE**
GPA [Grade point average]	1444	0.550***	0.09859	1258	0.718***	0.11625	1,192	0.558***	0.1159
Receiving scholarship	1444	0.0704*	0.02826	1258	0.0735**	0.02587	1,192	0.0662*	0.0295
Grade progression	1444	0.0689**	0.02619	1258	0.0778*	0.03234	1,192	0.0561	0.0310
Grade repetition	1444	-0.0259	0.01736	1258	-0.0167	0.02076	1,192	-0.0209	0.0218
Drop-out	1444	-0.0229*	0.01015	1258	-0.0413*	0.01877	1,192	-0.0293*	0.0115
Non-attendance	1444	-0.0201	0.01953	1258	-0.0198	0.02116	1,192	-0.0059	0.0226

Note: *Level of significance 10%; **level of significance 5%; ***level of significance 1%; Coef=coefficient; n=number; SE=standard error

As can be seen in Tables 3.6, 3.7, 3.8, and 3.9, Models 9 and 10 are suitable for impact analysis based on the value of multivariate distance and the stable condition of covariates.

Table 13: Balance check (Model 9)

Covariates	**Before Matching L1**	**After Matching L1**
Household Head (HH) Education (years)	0.19544	0.01208
HH Income (BDT per Year)	0.35626	0.04063
Family Size	0.1481	0.02886
No. of Immigrant Members	0.07966	0.0181
Access to Toilet	0.23645	8.1 X e^ (−15)

Table 14: Balance check (Model 10)

Covariates	**Before Matching L1**	**After Matching L1**
Household Head (HH) Gender	0.03389	9.8 X e^ (−16)
HH Education (years)	0.19595	0.00693
HH Income (BDT per Year)	0.35672	0.0542
No. of Immigrant Members	0.07969	0.03148
Distance from PBS (km)	0.22557	0.05959
Access to Toilet	0.13736	7.0 X e^ (−16)

As seen in the results for Models 9 and 10, the study confirmed that access to an SHS increased children’s GPA by approximately 0.55 points above those without access to an SHS, with this result statistically significant. Children who could study with an SHS benefitted more than those without an SHS with regard to receiving scholarships. The difference was approximately 8% more and is statistically significant. Grade progression was achieved by approximately 8% more children who studied under SHS lighting than those who did not have an SHS, with this result also statistically significant.

Grade repetition, drop-out, and non-attending children also decreased in the treated group (i.e., those with an SHS) compared to the control group (those without an SHS), but this result was not statistically insignificant.

3.6 Conclusion

This study has focused on the influence of light (i.e., indoor lighting) on students’ academic performance and school enrollment. Solar technology can possibly improve educational outcomes in rural areas. Children with access to an SHS spent more time studying and reading as a consequence of improved lighting [84]. The most important benefit of SHSs is that children can do their homework at night [98]. The study investigated the impact analysis using different models. The first test involved the relationship between solar lighting and students' "academic performance," while the second test was between solar lighting and students' "school enrollment." The results of this matching showed that the impact of solar lighting on children's education, academic performance, and school enrollment is positive and significant. Therefore, a significant relationship was found between good quality lighting and students' performance.

Children from households without access to electricity for lighting purposes have previously been found to be more likely than the average child to not attend school [99]. The current study's findings did not support this finding, with the effect of access to an SHS for lighting on non-attendance found to be insignificant. The importance of lighting in the home and its impact on student "performance." is an interesting issue and the current study also found some significant relationships. The lighting quality was found to have a direct effect on students' academic performance. The quality of lighting in educational spaces at elementary school has previously been found to enhance students' learning and academic performance [100]. The current study examined the effects of home lighting from an SHS on children's academic performance as well as on school enrollment. Good lighting in the home was found to better motivate students to learn. With good lighting at home, students are more relaxed and not sleepy in class, and they have the motivation to learn better. A good learning environment, including proper lighting quality, is an invisible motivation and encourages students in their learning. It allows them to focus on their tasks and thus to perform better in their subjects. Adjustments to home lighting can also increase students' level of attention and improve their performance.

Chapter 4: Conjoint Analysis of Consumers' Preferences for Future Organic Solar PV System

4.1 Introduction

Access to energy is an essential indicator for ensuring a smooth lifestyle for individuals as well as enhancing socio-economic development. In 2015, 1.1 billion people globally had no access to electricity and 300 million people of that disadvantaged total lived in India [101]. India is one of the largest growing economies in the world, with energy consumption also growing, and about 40% of the total energy use being in rural areas [102]. This situation is exacerbated by the high cost of grid expansion, the local market's inability to achieve a balance, and the limited progress in rural electrification. Increasing consideration of the goal of universal access to energy has therefore raised concerns about rural electrification and interest in technologies that go beyond centralized systems. India's rural areas are diverse, with large socio-economic disparity due to caste, level of education, and geographical position [103]. The success of any development policy depends on the views and attitudes of the consumer, and some rural electrification programs have failed due to not incorporating this aspect. The concept of the "diffusion of innovation" is essential and has been found in off-grid renewable energy program development [104]. In one study based on two villages from the Indian state of Odisha, it was shown that households' adaptation to solar energy depended on a set of socio-economic, demographic, and institutional factors including the government's approach to rural electrification [105].

When observing the development process of countries around the world throughout the twentieth century, electricity supply has undoubtedly played an important role in promoting progress in all social sectors, thereby improving people's well-being. In most developing countries, such as India, households used multiple fuels, such as kerosene, and electricity for lighting. Kerosene is known to cause indoor air pollution. An aggressive effort is needed to deal with these problems and for households to switch from kerosene to electricity [106]. Rural electrification is an essential factor for poverty alleviation and also enhances rural growth. In India, although the GDP growth rate is increasing at an average of 8%, the contribution of agriculture is negligible. This is the reason why the government of India wants electrification for all rural villages [102]. When rural electrification is implemented by many people, off-grid and grid-connected options are usually initiated in parallel, although the basis for selection is not clear. Both options are usually based on political interests or donor priorities. Appropriate resource assessments or analysis of the cost efficiencies of different approaches are often overlooked. Consumers tend to buy renewable energy components which are able to provide a stable supply of electricity from cheap plans with low price fluctuations [107]. Considering the major costs of providing electricity to a large population, the potential impact of this effort requires a more reasonable comparison of the choices. Today, the opportunity to overcome the development divide depends to a large extent on the availability of energy; therefore, it is necessary to better explore the relationship between energy and sustainable development in order to understand how energy can help reduce poverty [108]. It is also urgent to give more emphasis to consumers' preferences for how a suitable energy policy is to be implemented.

In rural areas, poor people are used to silicon or conventional solar PV systems. They always keep the existing system and face difficulty with accepting new technology. In the current study, an organic solar PV system is illustrated, with its function explained to enhance their understanding. Demonstration plays an important role when a consumer is choosing an appropriate solar home system. Respondents consider the system's features in their choice with the most visual presentation being the appearance of the solar panel, size, color, surface pattern, functional performance, and price. The information barrier is considered a significant obstacle to technology adoption. One study, based on a randomized control trial (RCT) conducted in 75 villages, Uttar Pradesh, India, showed that only a demonstration or marketing could increase the sale of solar home systems (SHSs), rather than easy access to credit [109].

The current study reports on a social and technical analysis of Indian rural consumers' preferences for a future organic solar PV system. A detailed review of the social aspects of energy demand was undertaken through questionnaires which sought responses on preferences for the pattern of electricity use, product design of a solar PV system, the system's lifetime, and the system's cost. Respondents indicated that they preferred a solar PV system that would work under bad weather conditions and, in helping to identify socially acceptable and technically viable energy options, they mentioned having a flexible tent with a rainwater harvesting facility.

4.2 Goal of this Study

This study sought to examine the preferences of consumers (in this case, rural people in India) for a future organic solar PV system based on the following pros and cons of the key features and functions of this system:

Pros:

- Lightweight and bendable and, thus, portable and de-mountable
- Translucent and therefore usable for windows and shading eaves
- Functioning under soft sunlight in the morning, the evening, and even in cloudy weather

Cons:

- Low conversion rate
- Short system lifetime

Understanding and addressing users' preferences on the pros and cons of new features of the future organic solar PV model could be assisted in the following ways:

- ✓ Impact of additional information (demonstration) on their preferences
- ✓ Social capital (trust among villagers) and preferences on portability and de-mountability
- ✓ Trade-off between the pros and cons.

4.3 Product Design with Organic Solar PV System

From a technical point of view, before commencing demonstrations, the contribution of the proposed technology to the disadvantaged region needed to be clear. Villagers should know the systems' advantages and weaknesses, and what would be possible by using the proposed system. Before starting the survey, it was necessary to have a practical product design of at least one or two systems, as their components needed to be established for the survey. However, only a small number of real organic solar PV systems is available; therefore it is difficult to identify what kinds of features are preferred. The way that the study selected the proper design is described below:

I. Conventional SHS: SHS that they already know or use.

II. Proposed SHS 1: Using a technical database only (Product Ideas A and B)

III. Proposed SHS 2: Modified through the survey

IV. Proposed SHS 3: Final design

Table 15: Positives and negatives of conventional solar PV system and organic solar PV system

Conventional silicon (Si) crystalline solar PV system	
Positives	**Negatives**
- Comparatively high generation efficiency, (high output voltage and current), ~20% - Long generation lifetime, ~15 years - Cheap (presently) - High reliability - Different size with changing the number of the cell series.	- Comparatively heavy owing to the top glass and aluminum frame - Performance degradation in increased temperature and angular light - Small cell scaling; single cell is around 4~5 W (153 mm x 153 mm)
Organic solar PV system	
Positives	**Negatives**
- Large cell scaling with use of roll-to-roll fabrication - Flexible (bendable) - Thin and lightweight - Designability (transparency, colorfulness) - Performance retention in weak illuminance conditions (cloudy weather and angular light)	- Weak for high temperature - Short generation life time, ~5 years - Low generation efficiency, (Low output voltage and current), ~11% - Expensive (presently)

Table 16: Comparison of conventional solar home system and study's proposed system

	Conventional SHS	**Proposed SHS 1 (Product Idea A)**
System components	Silicon solar panel (10W~150W), 15 years Glass top and aluminum frame Control BOX - Lead acid battery (12 V, 20 Ah), 5 years - Charge controller, 10 years -- LED light Mobile charge (cable) Small fan	Organic solar panel (10W~100W), 5 years Flexible and frame-less Control BOX - Lead acid battery (12 V, 20 Ah), 5 years - Charge controller, 10 years -- LED light (Organic EL) Mobile charge (cable) Small fan
Contributes to advantages and applications	A solar home system (SHS) to provide the necessary light for minimum daily life Education (study at night) Improvement for health conditions (× kerosene lamps, candles)	A solar home system (SHS) to provide the necessary light for minimum daily life with a lower price and additional functions Education (study at night) Improvement for health conditions (× kerosene lamps, candles) High design (flexible, transparent, colorful, lightweight, winding type)
Weaknesses and difficulties	Owing to the weight of the frame and covering glass, places in which it can be installed are limited; it requires a moderately tough structure. The bypass diode is necessary in cases of shady conditions. Disposal of the solar module: when the module is fully used or broken, it will be considered industrial waste → landfill garbage (environmentally harmful) Financial problem of the cost Maintenance and after care problems	Shorter lifetime Generation efficiency is lower than the silicon system; output voltage is also lower. Weakness in high temperature conditions. Extreme high temperature might cause chemical denaturation.. Financial problem of the cost Maintenance and aftercare problems

4.4 Target Area and Population

India is presently the world's seventh largest economy and the fifth largest energy consumer, recently overtaking China as the fastest growing large economy. However, around 30% of the total population have no access to grid electricity, and per capita energy consumption is very low at 530 kgoe (kilogram oil equivalent) while the world average is approximately 1800 kgoe. People living in urban areas can easily access electricity; on the other hand, people living in remote or mountainous areas have much less accessibility to the electricity grid. This considerable gap leads to strange statistics. The Indian government hopes that the expansion of renewable energy will fill the supply gap.

Several reasons were considered by the current study in the selection of villages, such as:

- A disadvantaged region in terms of geographical conditions and income opportunities.
- No national grid electrification.
- Some villagers already electrified with solar PV systems while some are still un-electrified; that is, to some extent, the villagers know about solar PV systems.
- Access to a very large government subsidy that supports the electrification of poor people's houses through the mini grid of a solar PV system.
- Initiatives and implementation policy undertaken by the Centre for Rural Education and Development Action(CREDA).

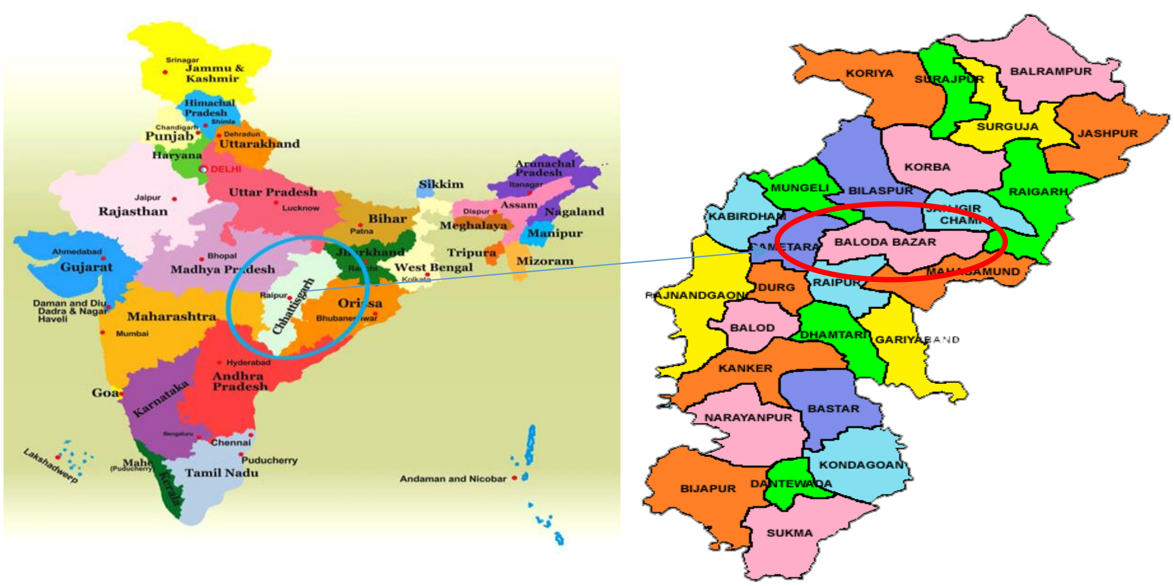


Figure 3: Map of Chhattisgarh state and Balodabazar district

Table 17: Chhattisgarh's vital indicators at a glance

Particulars	
No. of districts	18
No. of total villages	20,126
Total population	26 million
Poverty rate	40%
Literacy rate	71%
Electrification	87%
Access to drinking water	27%

Based on Population Census 2011. Source: World Bank

4.5 Data Collection

The pilot survey was conducted for eight days from March 5–13, 2017, collecting 54 responses on electricity use and 82 responses on product design from the following four villages: Rawan, Dhebi, Debhikhar, and Barnawapara. The main survey was conducted from September 8–18, 2017, after a little revision of the product design set of questions. The questionnaire was therefore modified, based on the pilot survey analysis.

From the pilot survey, it was confirmed that respondents understood the scenario and the choices. The main survey was conducted based on the product design questionnaire as the study's main aim within the on-site team project was to estimate consumers' preferences for an organic solar PV system. In the main survey, the intervention was the illustration picture of the proposed organic solar PV system, with flexibility plus a rainwater harvesting facility. The sample was categorized into two groups: the treatment group (109 respondents) and the control group (116 respondents). In both the pilot and main survey, the enumerator used the local language (Hindi) for communication and interpretation purposes to develop greater understanding of the questionnaire by respondents.

The flow of the data collection is shown below.

I. Interpretation from English to Hindi

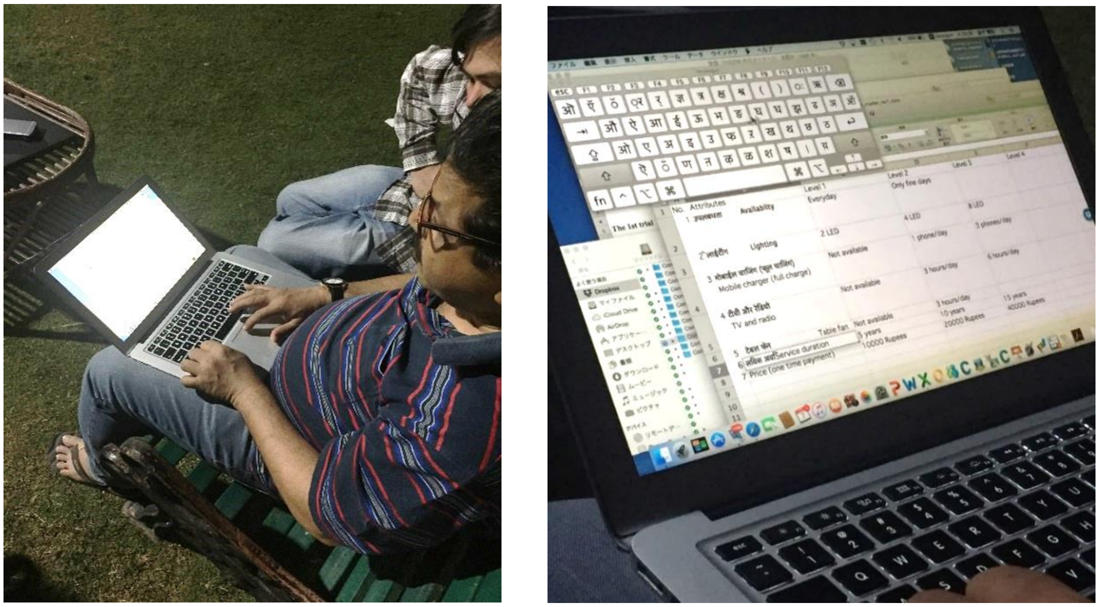


Photo 4.1: Interpretation from English to Hindi by Mr Rajeev

II. Instruction and practice for enumerators

Photo 4.2: Instruction and practice by Mr Rajeev and Professor Kaneko for enumerators

III. Obtaining respondents' completed questionnaires

Photo 4.3: Interview with local residents with a laptop-based explanation

Simple Random Sampling

The following criteria were used by the study for selection of households in the sample:

- Balodabazar district in Chhattisgarh was chosen as it was a disadvantaged region.
- Villages were chosen for a purposive study
- Households were randomly selected from the listed villages.

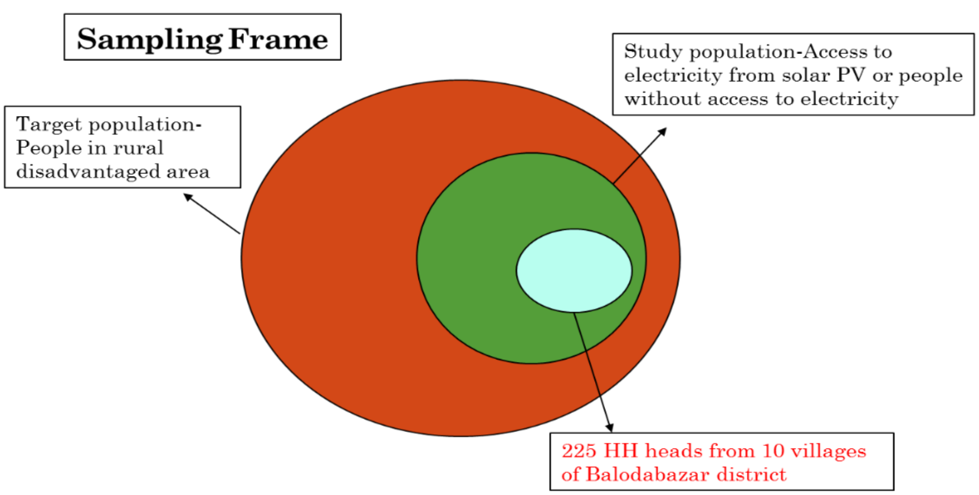


Figure 4: Sampling frame of village selection for survey

Table 18: Village breakdown by number of respondents (treatment group)

Name of Village	No. of respondents
Bar	12
Dond 1	32
Dond 2	17
Loritkhar	16
Mohda	18
Gudagarh	14
Total	109

Table 19: Village breakdown by number of respondents (control group)

Name of Village	No. of respondents
Amgaon	10
Dheba	27
Dhebi khar	23
Kawabahara	16
Dond 2	12
Rawan	23
Others	5
Total	116

The seven attributes and their respective levels provided 648 sets of choices, two of which were randomly paired, including the status quo for electricity use, while, for product design, 575 sets of choices were provided. Each respondent was required to make a ranking decision six times for three different choice sets. In both conjoint experiments, a laptop computerized record with the Microsoft (MS) Excel Macro program was used for data collection.

Table 20: Summary statistics of respondents (main survey)

Variable	Observation	Mean	Std. Dev.	Min	Max
Age	1,284	37.24299	14.71655	14	75
Gender	1,260	1.085714	0.2800528	1	2
Years of schooling	1,272	8.198113	3.602831	0	16
Electrified (yes/no)	1,296	0.8611111	0.345964	0	1
Years of electrification	1,128	11.64043	4.06548	0	25
Private SHS (yes/no)	1,248	0.4326923	0.4956476	0	1
Years of SHS use	540	6.377778	4.813196	1	25
Price of SHS	540	6633.333	2314.911	1000	13000
LEDs	1,176	3.377551	1.515977	0	8
TV	1,236	0.631068	0.4827108	0	1
Hours of TV watching	852	2.394366	1.497155	0	8
Mobile phone (yes/no)	1,296	0.8055556	0.3959252	0	1
Number of mobile phones in family	936	1.474359	0.9165062	0	6

4.6 Conjoint Method

The conjoint analysis used the data to construct quantitative models to estimate consumers' preferences for the product attributes. Conjoint analysis is widely used in marketing to measure consumers' preferences, forecast demand, and develop products [110] [111]. The two types of conjoint analysis are: (1) choice-based conjoint analysis (known as a discrete experiment); and (2) rating-based conjoint analysis. The current study applied the choice-based conjoint experiment to estimate respondents' preferences on organic SHS electricity use and product design. In a choice-based conjoint experiment, respondents are usually asked to choose combinations of attribute levels, which are referred to as profiles. The profile design is also random. The current study used only a small number of profiles and a restricted number of respondents due to time and budgetary constraints.

The randomization of the conjoint experiment was arranged as follows. Respondents were selected randomly from a homogeneous population. They were comparable regarding age, gender, economic status, electrification status, etc. Due to the similar setting, the typical scenario was obtained from the rated profiles.

Two types of conjoint analysis were conducted: electricity use and product design of the solar home system (SHS):

- ❑ Combined two conjoint surveys: (**Pilot survey, March 2017**)
  - Use of electricity services and product design choice
  - Incorporation of some key features and functions unique to the organic solar module
- ❑ Demonstration as treatment: **(Main Survey, September 2017)**
  - With/without demonstration
  - Before/after demonstration
- ❑ Level of knowledge and experience of existing solar home system (SHS)
  - Controlled by careful selection of the villagers

In one version, the choice set has two alternatives (A vs. B) from which respondents must choose one over the other. In another version, the choice set includes a third alternative, namely, the existing situation, referred to as the status quo. If the respondent does not choose from the first two alternatives, then he/she can choose the third alternative. The current study has at least two variations: one is selecting the best options, and the other is ranking the other options.

Hainmueller et al. [112] applied the randomized experimental design of conjoint analysis from the revised conventional conjoint analysis framework that estimates the effect of causal components on respondents' stated preferences without bias, thus extending beyond the findings from previous methodological literature. The average marginal component effect can be calculated as follows:

$$y_{itj} = \beta_0 + \sum_{l=1}^{7} \sum_{d=2}^{Dl} \beta_{ld} \times a_{itjld} + u_{itj}$$

where a_{itjld} =dummy variable

(for the $l-$level of an attribute *l* of a policy *j* in task *t* of respondent *i*)

Dl=number of levels of an attribute

β_{ld}=coefficient

u_{itj}=error terms

$y_{itj}\epsilon$ {0, 1}=a choice indicator variable.

The approach has two advantages: (i) conditional independency must hold as attributes are purely randomly ordered for each respondent, and (ii) the causal effects can be estimated non-parametrically as all explanatory variables are dummy variables.

Internal Choice Probability: Policy is preferred to the alternative policy. This compares the ranking between two proposed choice profiles in which ranking 1 is assigned to an alternative with a higher ranking, and 0 otherwise, irrespective of the ranking of the status quo.

External Choice Probability: Policy is preferred to the status quo. This compares the ranking between the status quo and two other alternatives. If 1 is assigned to any choice set, then it reveals a higher ranking than that of the status quo, and 0 otherwise. If the classification of the status quo is the highest or lowest, both two choice sets are assigned zero (0) or 1.

4.7 Motivation for Selecting the Attributes for Product Design

Several factors affect consumers' preferences for a product, such as price, function, performance, product familiarity, external factors, information, durability of that product, etc. Many studies have been conducted on the electric vehicle (EV), seeking consumer preference factors. Consumer willingness to buy an electric vehicle (EV) is based on some of the vehicle's technical specifications. One study has shown that consumer willingness to buy an EV depends on increasing the battery lifetime, reducing the charging time, and increasing the EV's range. A logistics model was conducted based on the perception of price, age, battery lifetime, charge times, and range. The research covered 1245 respondents from Spain [113]. Electric vehicles (EVs) are regarded as being environmentally friendly with the potential to reduce greenhouse gas emissions. Electric vehicle (EV) adoption depends on financial incentives, charging infrastructure, local production facilities, etc. Multiple regression models have shown that, among all factors, charging infrastructure was most strongly related to EV adoption [114]. Electric vehicle (EV) adoption requires three tactics: reducing the vehicle price through a subsidy, a local public charging network, and, through government fleet purchase, expanding the number and perceivability of completely battery electric vehicles (BEVs) on roadways, as well as a hybrid mix of these three tactics. That research has shown that the hybrid policy option was the best in encouraging BEV selection [115]. Electric vehicles (EVs) are an alternative solution for reducing high dependency on fossil fuel, high carbon dioxide emissions, and addressing other environmental issues. However, consumers do not have good perceptions of electric vehicles (EVs) due to the possible drivers for and, more specifically, the barriers to EV adoption. Thus, it is essential to understand consumers' intentions and behavior in order to increase EV adoption [116]. The consumer is very concerned about some EV indicators such as battery range, cost, and charging infrastructure. The significant barriers to EV adoption are battery technology and sustainability of fuel sources. The commercial success or failure of EVs depends on consumer attitudes and acceptance [117].

Several types of research have been conducted on the characteristics and benefits of the solar home system (SHS). One field survey assessment in Assam, India, evaluated the technical performance of SHSs, service delivery, institutional arrangements, user satisfaction, and benefits for rural livelihoods, with cost the primary barrier to SHS adoption [78]. User satisfaction with the SHS depends on SHS equipment, reduction of energy costs, extending children's study hours, etc. A key finding is that the quality of SHS equipment and lifestyle benefits from the SHS play a significant role in improving user satisfaction in rural Bangladesh [35]. Conjoint analysis was also used for estimating consumers' preferences for color, shape, pattern, and SHS frame as well as examining the trade-off between solar panel appearance, functional performance, and price [118]. In the current study, conjoint analysis was used to estimate consumers' preferences for the solar panel and included some existing features as well some hypothetical ones, such as the organic solar PV system. Consumers' prior knowledge of a product is an essential factor that also affects the stability of their preferences [119]. The consumer can make a choice quickly if they know the primary attributes of the product. With an unfamiliar product, the consumer cannot make a smooth preference. The consumer's preference also changes if they see the characteristics of the product. They may evaluate or recall some product characteristics during the process of choosing a product. The success of any development policy depends on the views and attitudes of consumers; some rural electrification programs have failed for not incorporating the consumer perspective. The concept of the "diffusion of innovation" is important and is found in off-grid renewable energy program development [104].

The current study examined consumers' preferences for the proposed organic solar panel based on the following seven attributes: system design of panel and battery; panel size and features; translucency; chargeability in cloudy weather; system lifetime; price; and print design on the panel surface. The attributes were selected from previous studies' findings on preference indicators for electric vehicles (EVs) and SHSs that broadly examined some important factors. A demonstration of the picture of the panel was undertaken to capture consumers' preferences for the proposed organic solar PV system.

4.8 Ideas for Treatment (Demonstration) in the Survey

A demonstration plays an important role when deciding on the choice of an appropriate solar home system (SHS). The features of such a system include the following:

- ❑ Panel size
- ❑ Functional performance
- ❑ Surface pattern
- ❑ Color.

Respondents chose better-looking SHSs with better functional performance despite the high price [118]. The points that the study needed to consider in the treatment was that it must be time efficient and understandable for villagers.

Some of the ideas for the treatment were as follows:

- Idea A: Bring only ***pictures or illustrations*** of the organic solar panel to the village and show them while providing a brief explanation.
  Time efficiency: Very High; Understandability for villagers: High
  Technology participation: Low; Cost: Very Low

- Idea B: Bring some ***real devices***, such as a flexible organic solar panel to the village so villagers can see and touch them in real life.
  Time efficiency: Low; Understandability for villagers: Very High
  Technology participation: Medium; Cost: High

- Idea C: Bring a ***developed solar panel*** which has a boost converter circuit (Hiroshi is engaging) and show the circuit's function.
  Time efficiency: Very Low; Understandability for villagers: Very Low
  Technology participation: Very High; Cost: Very High

The current study adopted Idea A as the treatment as it was time efficient and could help villagers to imagine the idea of the product at a glance. Also, the study needed to collect the data with some teams simultaneously aiming at an adequate sample size. Idea B was good as it showed them a real device to gain their interest in the survey, however, it was still difficult to explain features of the new product, such as tents or shading eaves. Idea C made a good contribution to the technology, but this was irrelevant as the study was not seeking to collect responses on the boost circuit function. Plus, Ideas B and C incurred more costs and it would also take time to prepare the devices.

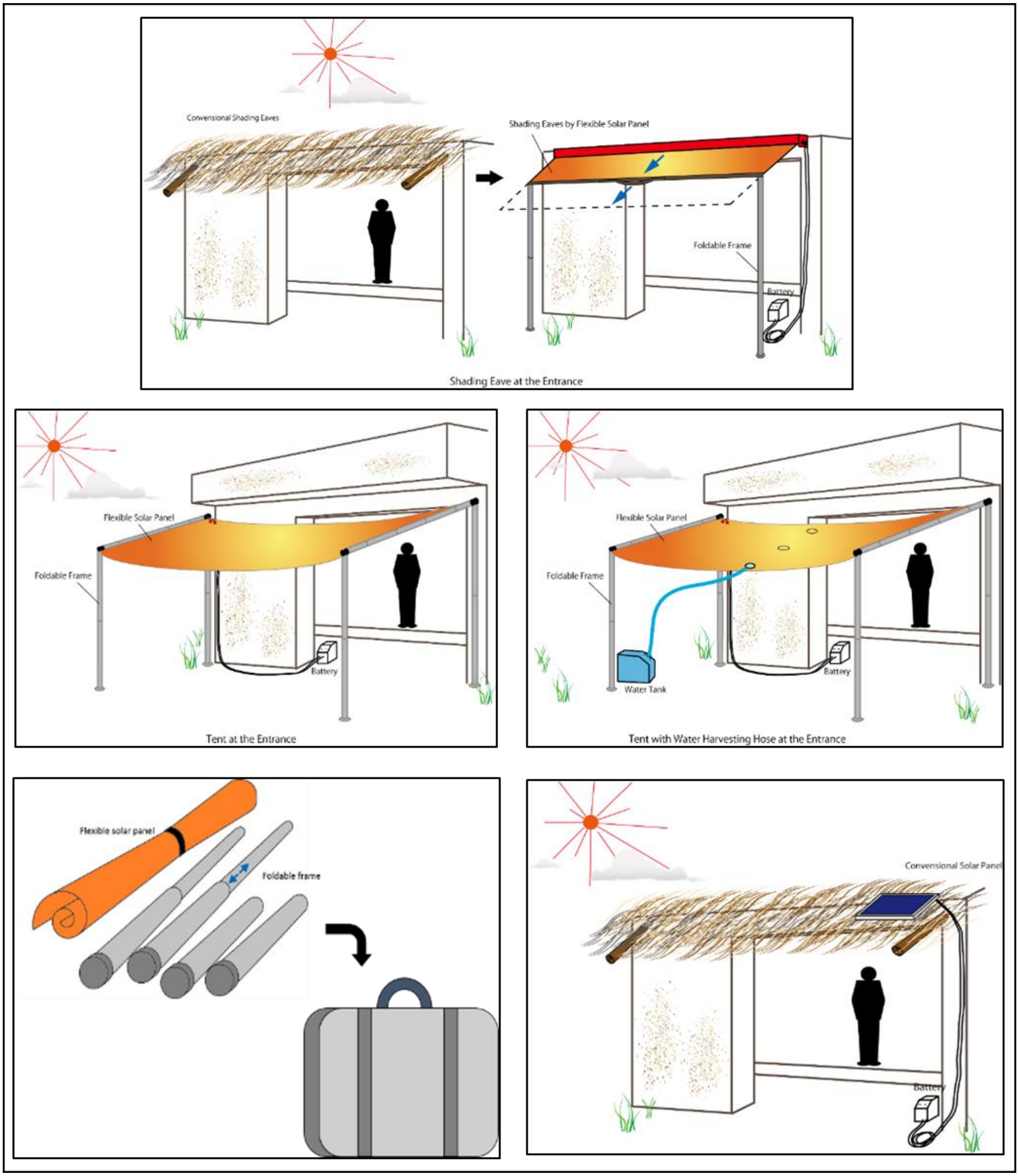


Figure 5: Illustrations used in main survey

4.9 Findings and Discussion

4.9.1 Pilot Survey

The following two types of conjoint analysis were conducted during the pilot survey (in March 2017):

1. Electricity use
2. Product design

Information about the electricity use pattern was collected from the local people (the villagers). The study sought to learn the real demand for electricity in their daily lives and to identify their priorities for the uses of electricity. In total, 54 heads of households were interviewed to develop the actual scenario of the electricity use pattern through the randomized conjoint experiment. The attributes of the survey were: availability, lighting, mobile charge, TV and radio, table fan, service duration, and cost.

The study proposed the future organic solar PV system to existing users and non-users in order to examine their preferences for the attributes, with these comprising the existing features of the conventional solar PV system as well the features of the organic solar PV system. The study interviewed 40 heads of households requesting them to choose from the set of choices based on these attributes, such as detachability, mounting, full charge under sunny weather, de-chargeability under cloudy weather, product lifetime, and cost. Some attributes were changed, while new attributes were included based on the pilot survey and its results. The new attributes included were panel size and print design on panel surface, with the study then interviewing another 42 heads of households based the new choice sets.

4.9.2 Results of Electricity Use

Two types of estimators were applied to estimate the choice probabilities, namely, internal and external choice probability. Figure plotting was used for the purpose of analysis. The study interviewed 54 respondents who were either heads of households or eligible family members, with each respondent asked six times to choose a preference from different choice sets.

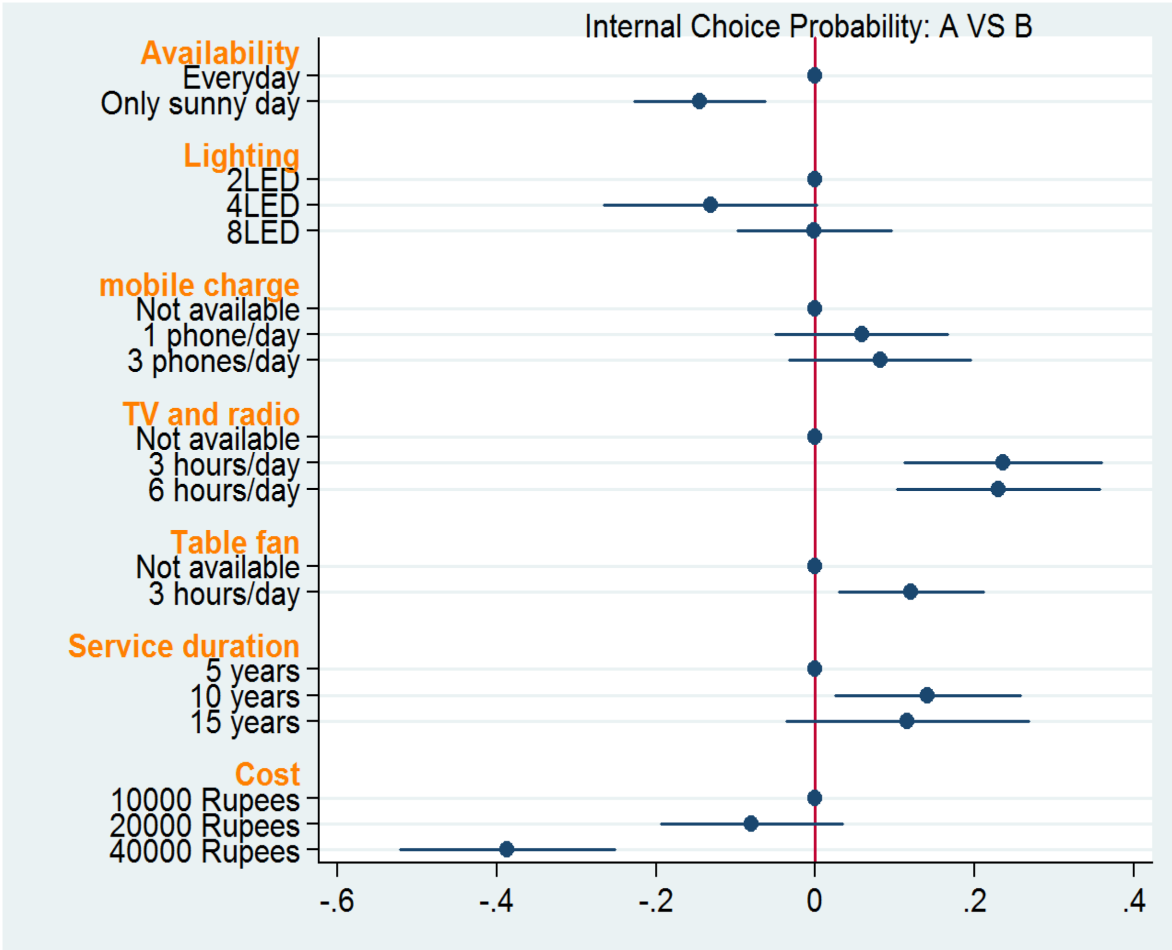


Figure 6: Average causal effects on internal choice probability

As shown in Figure 4.4, based on internal choice probability, the probability was to choose the policy rather than the alternative policy. It was found that the attributes of 'Availability,' 'TV and Radio,' and 'Table fan' had a statistically significant positive effect, while no significant effects for the attributes of 'Lighting,' and 'Mobile charge' were observed. On the other hand, the level of the higher burden of the 'Cost' was less preferable and statistically significant.

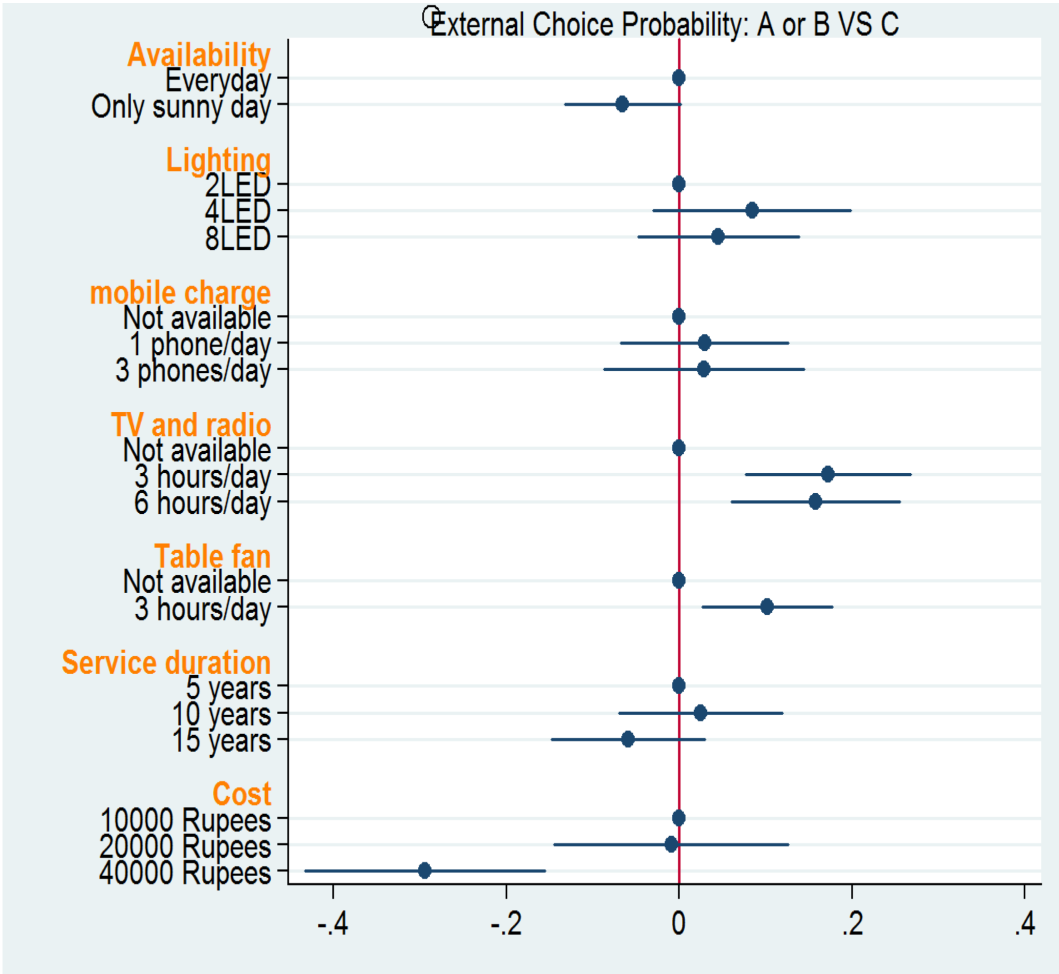


Figure 7: Average causal effects on external choice probability

As shown in Figure 4.5, for the attributes of 'TV and radio', the level of three hours/day was positive and statistically significant, as well as the level of six hours/day. Using the attribute of 'Table fan' three hours/day was also positive and significant. The lower 'Cost' of the system was also preferable. For the other attributes, no significant result was found in the external choice probability.

4.9.3 Results of Product Design

In terms of product design, the study interviewed 40 respondents on attributes such as detachability, mounting, full charge under sunny weather, chargeability under cloudy weather, system lifetime, and cost of the system. The study repeated the request to each respondent to choose a preference six times using different choice sets.

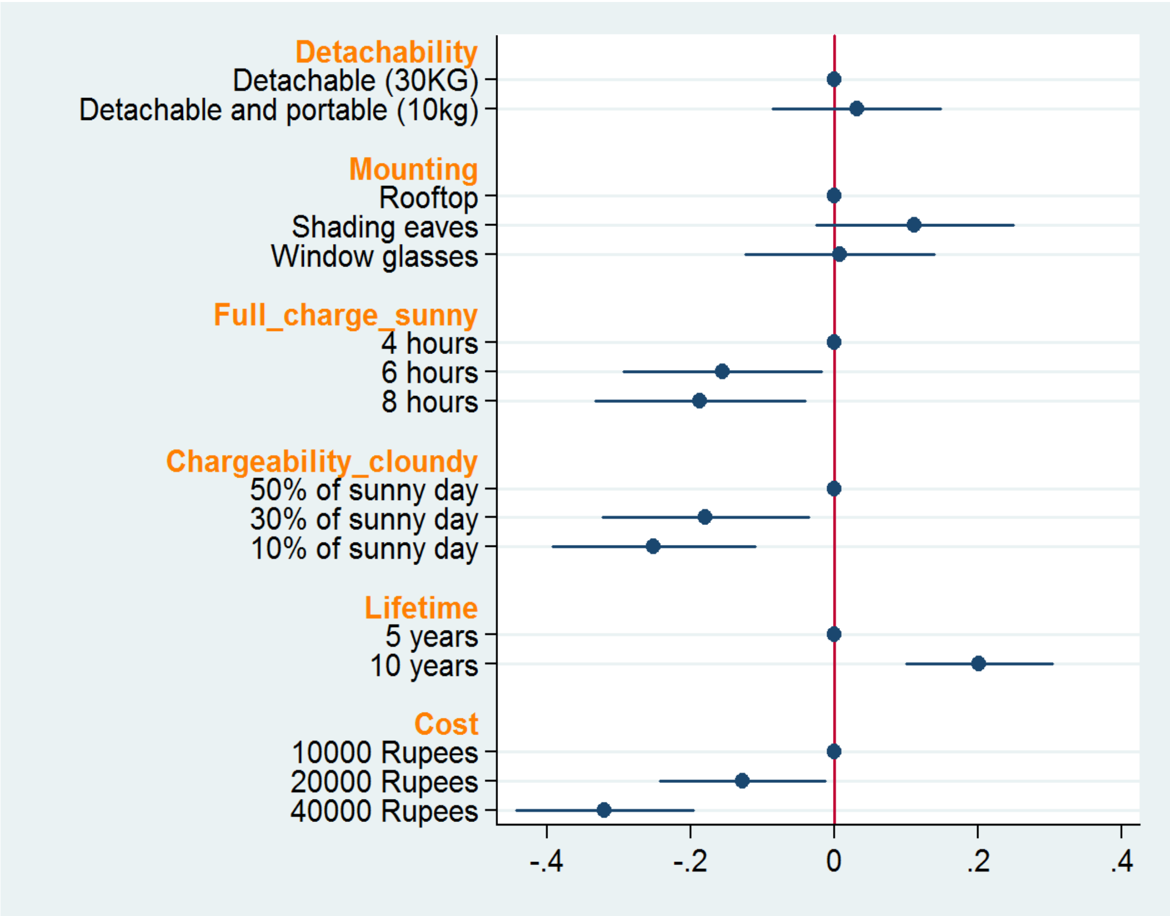


Figure 8: Average causal effects on internal choice probability

As shown in Figure 4.6, the attributes 'Full charge under sunny weather,' 'Chargeability under cloudy weather,' 'Lifetime,' and 'Cost' had results that were significant. Less hours for 'Full charge under sunny weather' was preferable to more hours. No significant result was found regarding the attributes 'Detachability' and 'Mounting'.

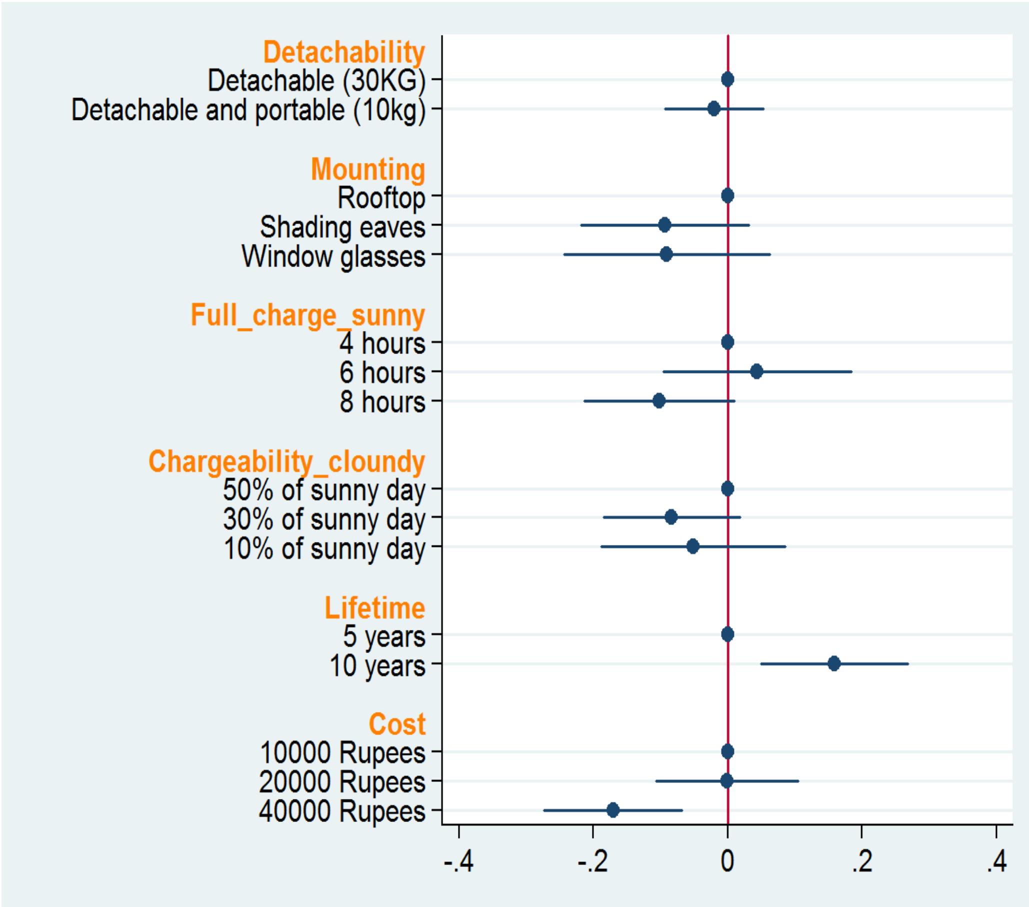


Figure 9: Average causal effects on external choice probability

As shown in Figure 4.7, most attributes were insignificant, except for the level of a long 'Lifetime' (10 years) and the level of high 'Cost' (40,000 rupees). A longer system lifetime was preferred over a shorter system lifetime. The high cost of the system was less preferred to less cost for the system.

4.9.4 New Scenario for Product Design 1

As no significant preferences were indicated by respondents, the current study added new attributes. These new attributes were 'Panel and battery,' 'Panel size,' and 'Translucency.' These kinds of attributes include the features of an organic solar PV system. A survey was conducted among only 10 respondents based on these new attributes.

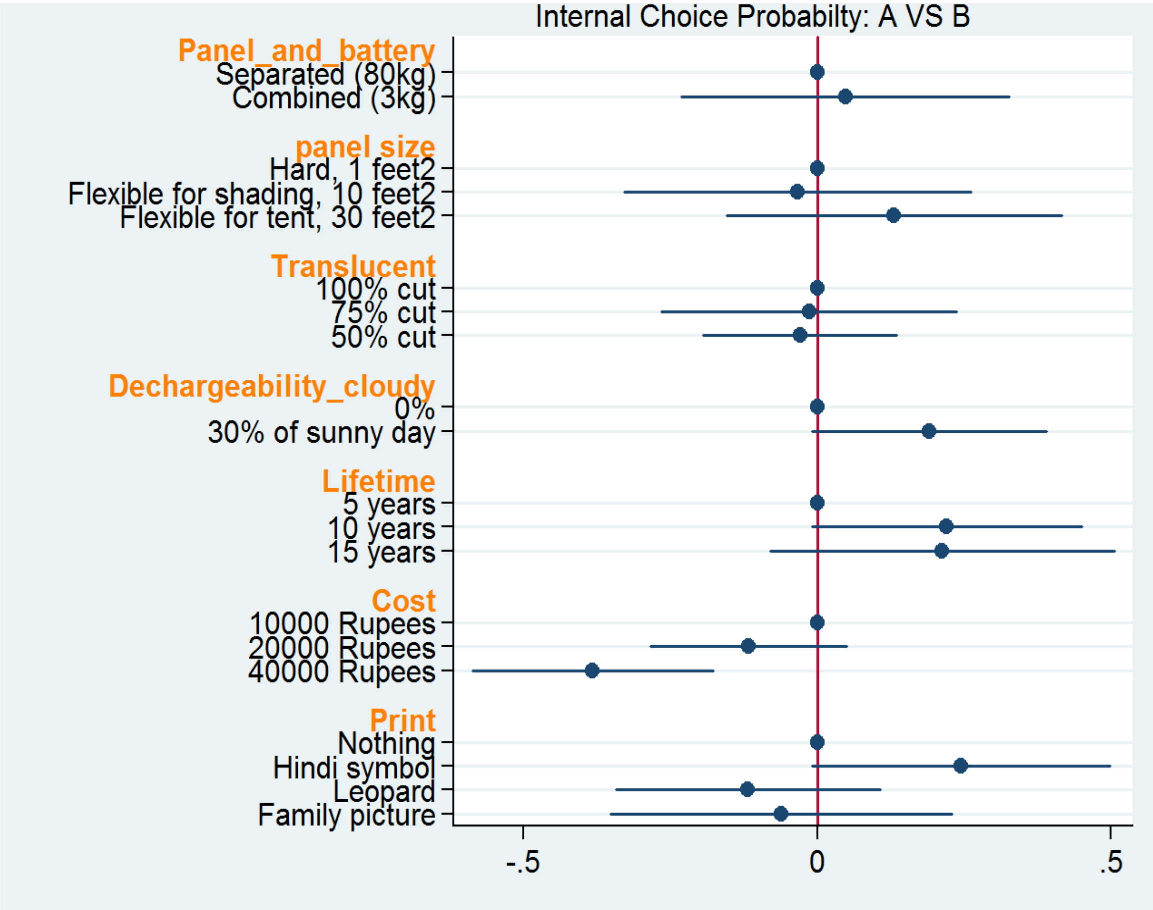


Figure 10: Average causal effects on internal choice probability

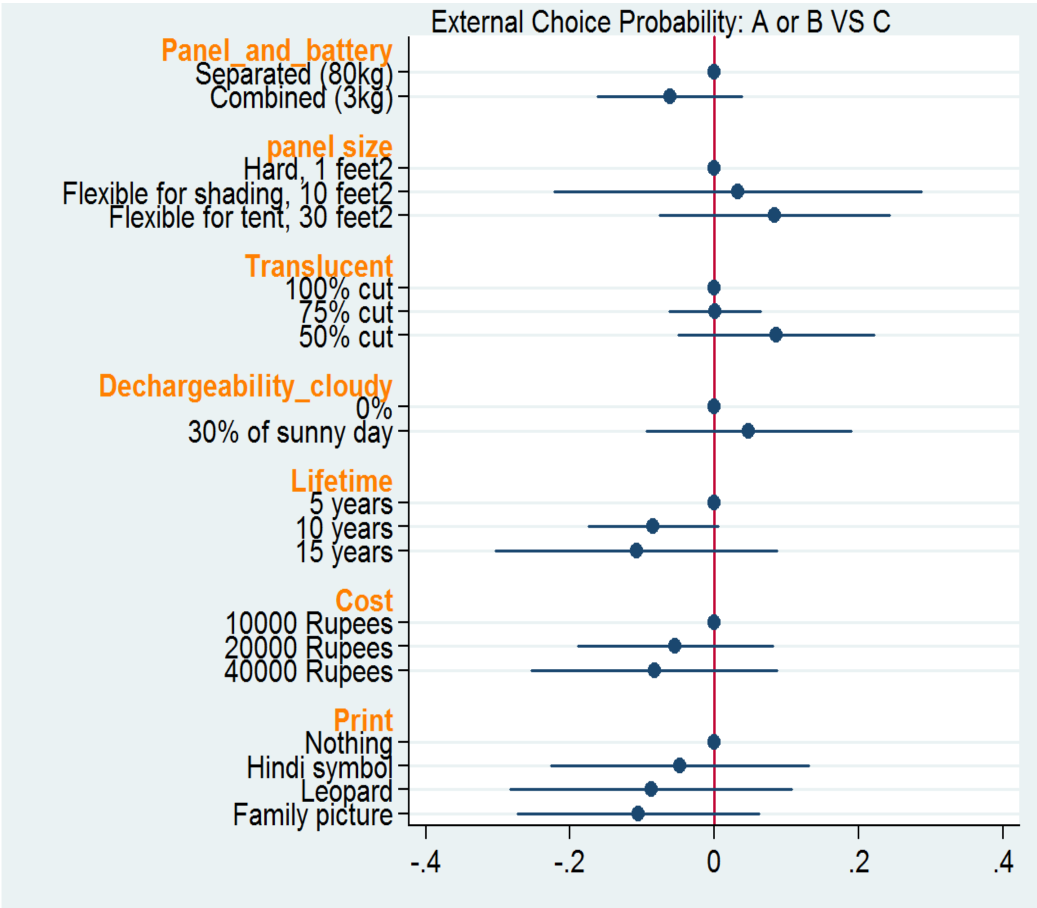


Figure 11: Average causal effects on external choice probability

No significant result was obtained for preferences in either internal or external choice probability. Possible reasons were the lack of respondents' proper understanding of the new attributes and the small sample size.

4.9.5 New Scenario for Product Design 2

The study's attributes were again changed a little based on an analysis of the findings on the new Product Design 1 scenario. The level of 'leopard' was removed from the attribute of 'Print' and one important level was included, named 'flexible tent plus rain harvesting,' in the 'Panel size' attribute for greater validity of the current research. The study interviewed 32 respondents and requested each respondent to indicate their preference six times using different random choice sets.

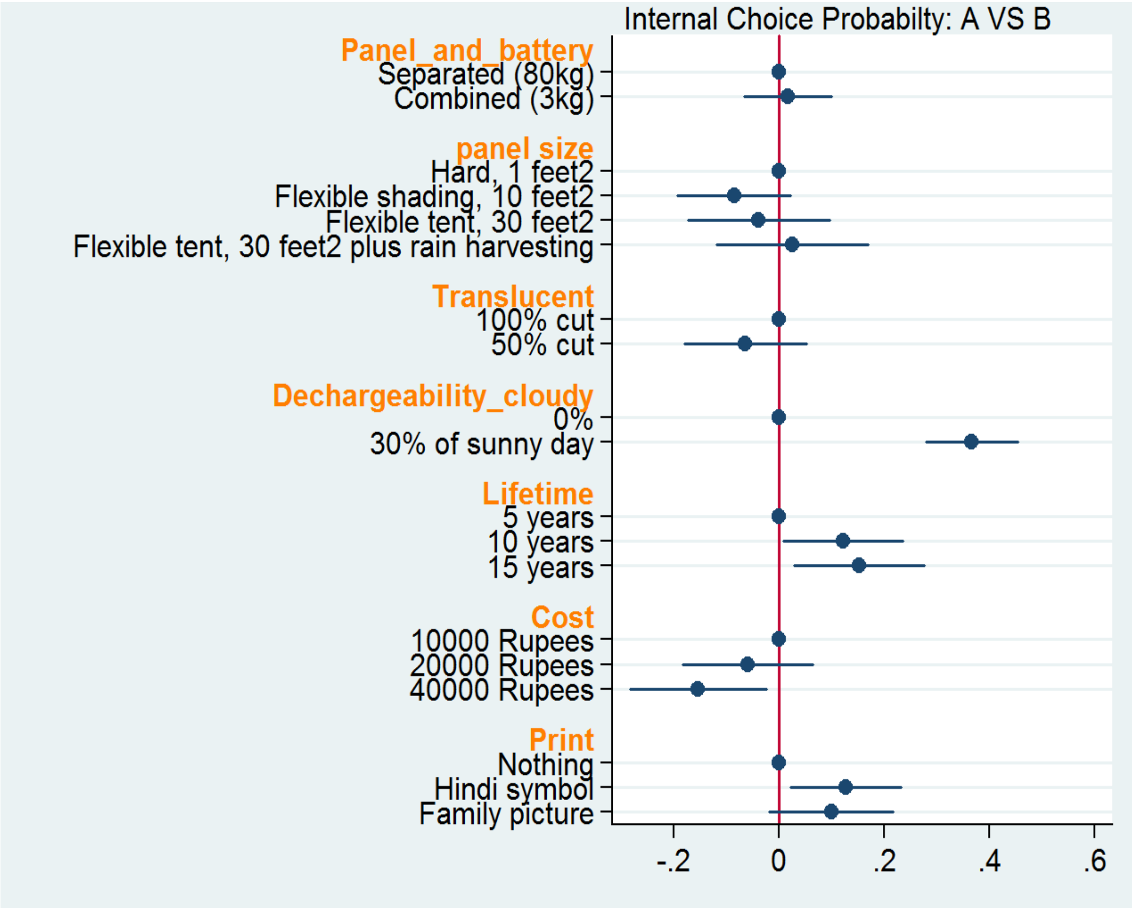


Figure 12: Average causal effects on internal choice probability

As shown in Figure 4.10, the 30% level of ‘De-chargeability’ on the sunny day is positive and statistically significant. Less ‘Cost’ of the system is also positive and significant. The level of the ‘Hindi symbol’ was positive and significant. On the other hand, the level of the ‘family picture’ was positive but insignificant.

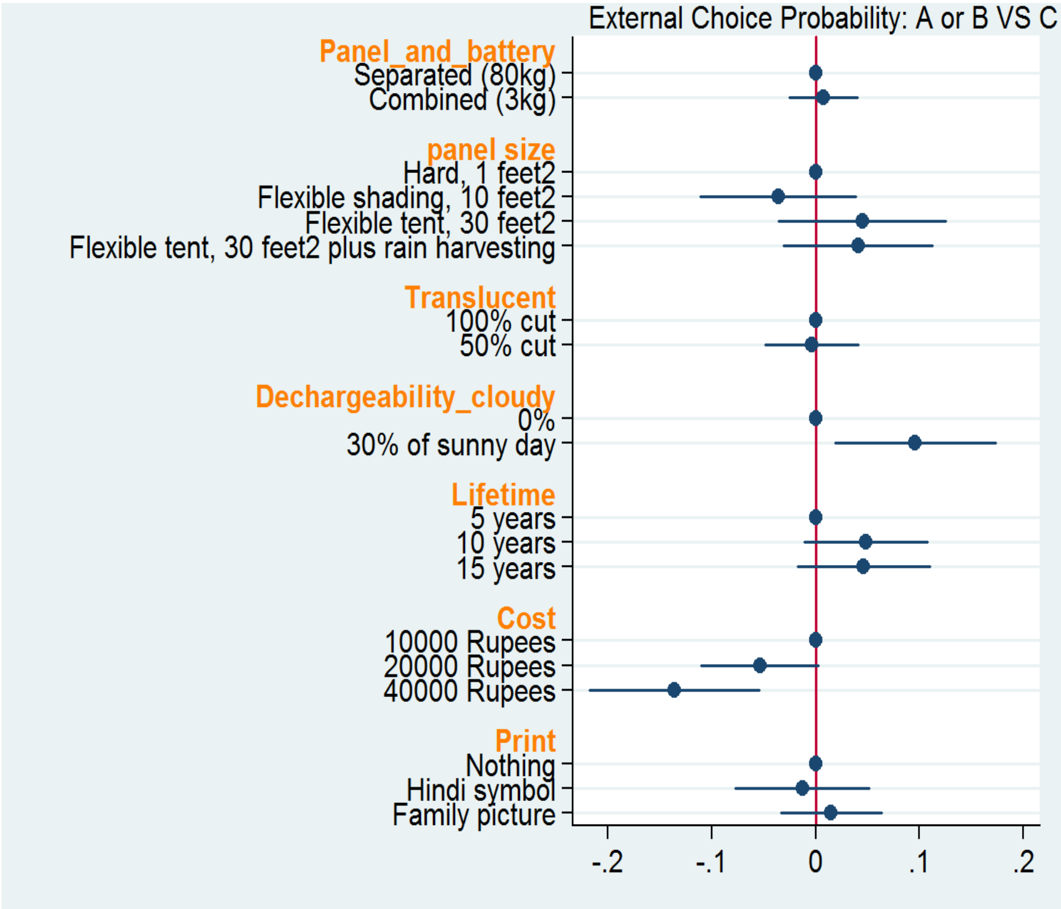


Figure 13: Average causal effects on external choice probability

As shown in Figure 4.11, the level of 30% of sunny day for 'De-chargeability' over the 'De-chargeability under cloudy weather' attribute was positive and statistically significant. The system 'Cost' of '40,000 rupees' was negative and statistically significant.

4.10 Main Survey

Based on the pilot survey, several factors, such as price, system cost, de-chargeability under cloudy weather, and system lifetime were found to play an important role in choosing preferences from the hypothetical profile choice sets in the research design. The study's aim was also to learn consumers' preferences for some features (e.g., panel size and translucency) of the organic solar PV system. No significant result was found for either attribute. Further research was undertaken on the organic solar PV system features and consumers' technology adoption behavior.

The main survey was conducted from September 7–17, 2017, in which more than 225 heads of households were interviewed on the following intervention and procedure:

1. Treatment group: Pictures of the panel size and some functioning features were shown to respondents for their greater understanding. The enumerator also explained the function and benefit of the panel size, using the local language.
2. Control group: No demonstration was carried out of the picture and the enumerator undertook the interview based on hypothetical choice sets.

4.10.1 Treatment Group

To observe the experiment's effect, a group of objects was deliberately processed. In the experiment, the treatment was applied by the researcher to the experimental unit. The treatment of the study was a demonstration of the flexible organic solar PV system. This system is currently still undergoing experimentation in the laboratory. The local people had first heard of the term but were not able to imagine the kind of system it was. They did not know the functions and advantages of the organic solar PV system, so the current study conducted a demonstration to them, with this considered to be the study's intervention.

The panel size picture was demonstrated, with this including features of flexibility, foldability, and use as a tent and as a rainwater harvesting facility. A brief explanation was also made by the enumerator regarding the advantages and functions of the proposed organic solar PV system. In total, 110 respondents participated.

Figure 14: Average causal effects on internal choice probability

For the 'Panel size' attribute, the level 1 'flexible shading, 10 square feet' was estimated to increase the respondent's choice probability for supporting the panel's flexibility by about 15% compared to the baseline position (hard, 1 square foot). The level 2 'flexible and foldable tent, 30 square feet' and level 3 'flexible and foldable tent, 30 square feet plus rainwater harvesting' were preferred more than the baseline by 16% and 20% of respondents, respectively.

For the 'De-chargeability under cloudy weather' attribute, the level 1 '30% of sunny day' was estimated by about 38% of respondents compared to the baseline level.

For the 'Lifetime' attribute, the level 1 '10 years' has the potential to increase the probability by about 18% against the baseline '5 years' level and, for level 2 '15 years' by about 35% against the baseline level.

For the ‘Cost’ attribute, the level 2 ‘40,000 rupees’ had the potential to decrease the probability by 20% compared to the baseline level ‘10,000 rupees.’

For the ‘Panel battery’ and ‘Translucent’ attributes, no clear evidence for the choice probability estimation was found, despite the positive sign of the 50% level cut for the ‘Translucent’ attribute.

For the ‘Print’ attribute, the level of the family picture was positive but insignificant.

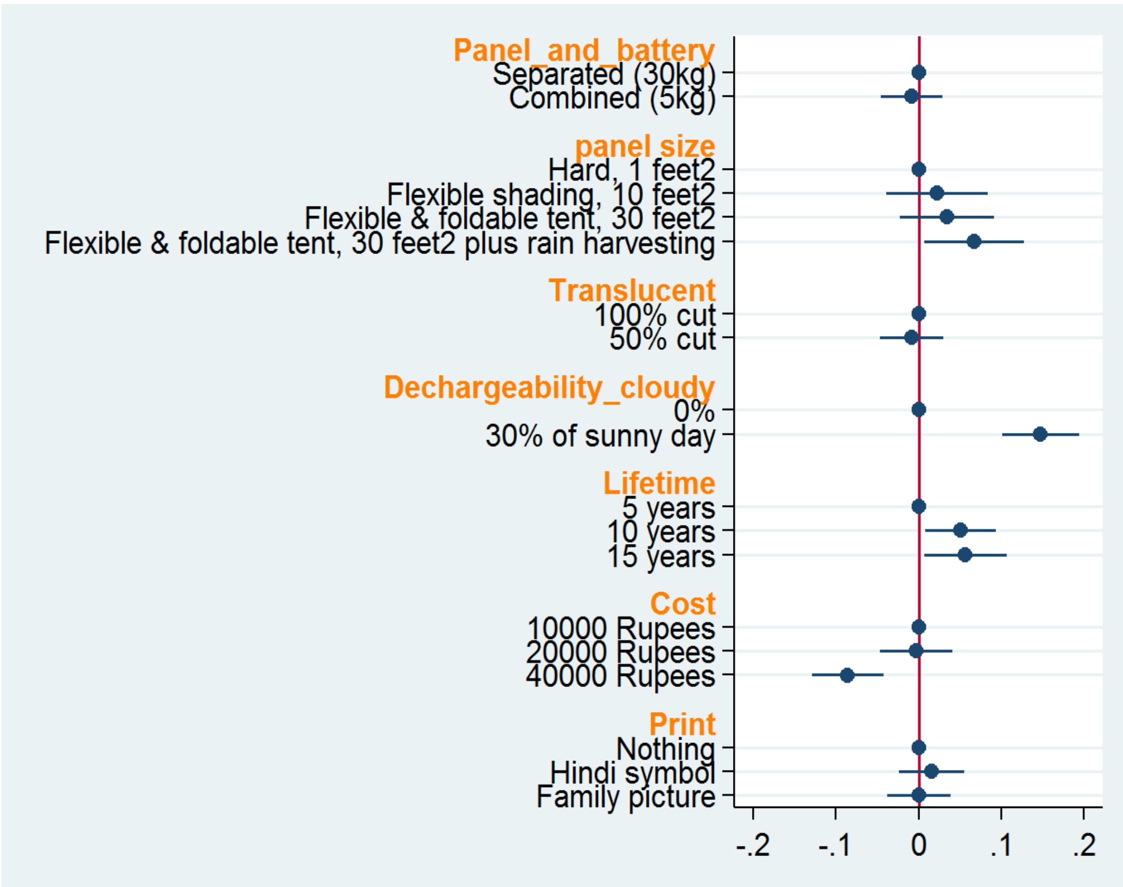


Figure 15: Average causal effects on external choice probability

As shown in Figure 4.13, the level of ‘flexible and foldable tent plus rainwater harvesting’ from the ‘Panel size’ attribute had the potential to increase the choice probability by 10% compared to the baseline level. The level of ‘30% of sunny day’ under the ‘De-chargeability under cloudy weather’ has the potential to increase the choice probability by 18% against the baseline level. In addition, a longer ‘Lifetime’ of the system was preferable to a shorter ‘Lifetime’ of the system.

4.10.2 Control Group

The study interviewed about 115 respondents without showing them the panel size picture. The discussion about the function of the proposed panel size was not based on the picture, with the interviews based only on the hypothetical choice sets.

Figure 16: Average causal effects on internal choice probability

As shown in Figure 4.14, the attributes of 'De-chargeability under cloudy weather' and 'Lifetime' were positive and significant compared to the baseline level. The lower 'Cost' of the system was preferable to the higher 'Cost' of that system.

For other attributes, such as 'Panel and battery,' 'Panel size,' 'Translucent,' and 'Print,' no significant evidence was found for the estimation in the internal choice probability.

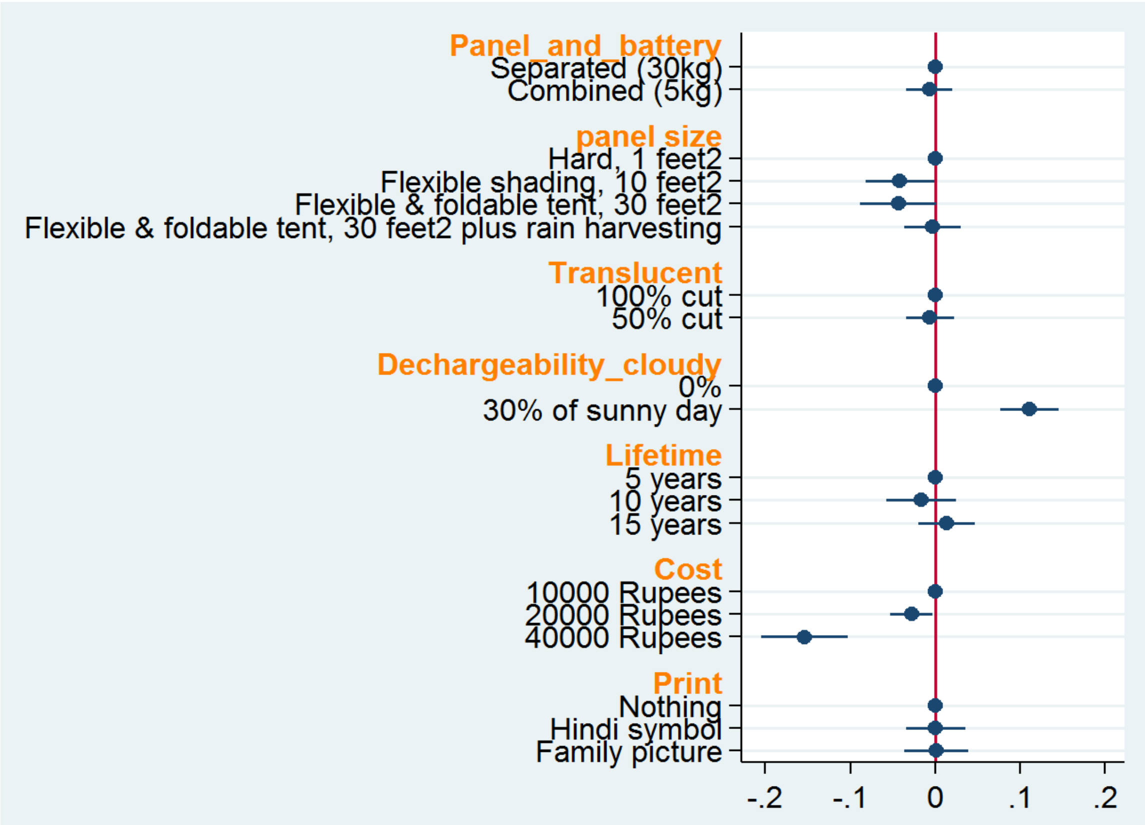


Figure 17: Average causal effects on external choice probability

For the attribute ‘De-chargeability under cloudy weather’, the level of ‘30% of sunny day’ was estimated to increase the respondent’s choice probability for supporting the organic solar PV system by about 15% compared to the baseline position of ‘0%’.

For the ‘Cost’ attribute, the level 2 ‘40,000 rupees’ has the potential to decrease the probability by about 16% against the baseline ‘10,000 rupees’ level.

4.10.3 Interaction Effect

The two types of interaction effects in conjoint analysis are: (i) interactions between the attributes; and (ii) interactions of the attributes with the respondent’s background characteristics. From the analysis the choice probability, it can be seen that respondents preferred the low cost of the system rather than the high cost. For that reason, the study set out to check the interaction effect between cost and other attributes.

Treatment group

From both the internal and external choice probability, it was seen that the interaction effect of cost and other attributes was negligible. The study's randomized designs of choice sets were therefore unbiased.

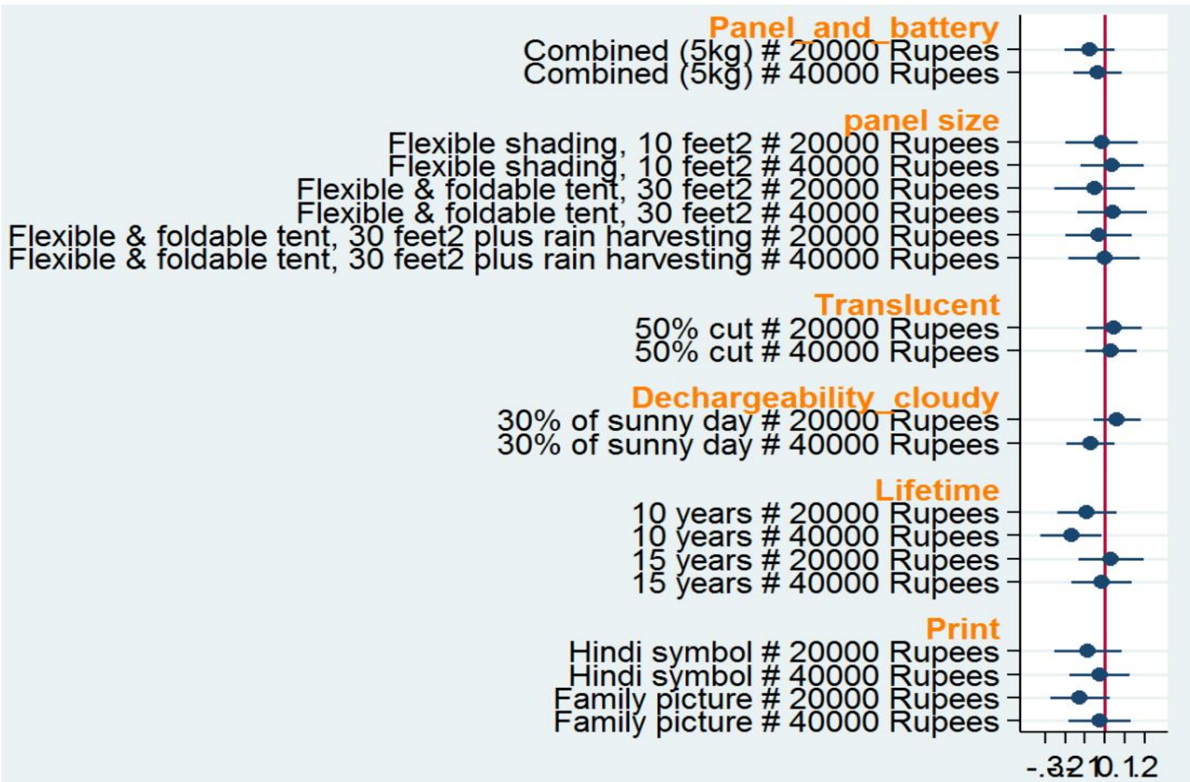


Figure 18: Average causal effects on internal choice probability

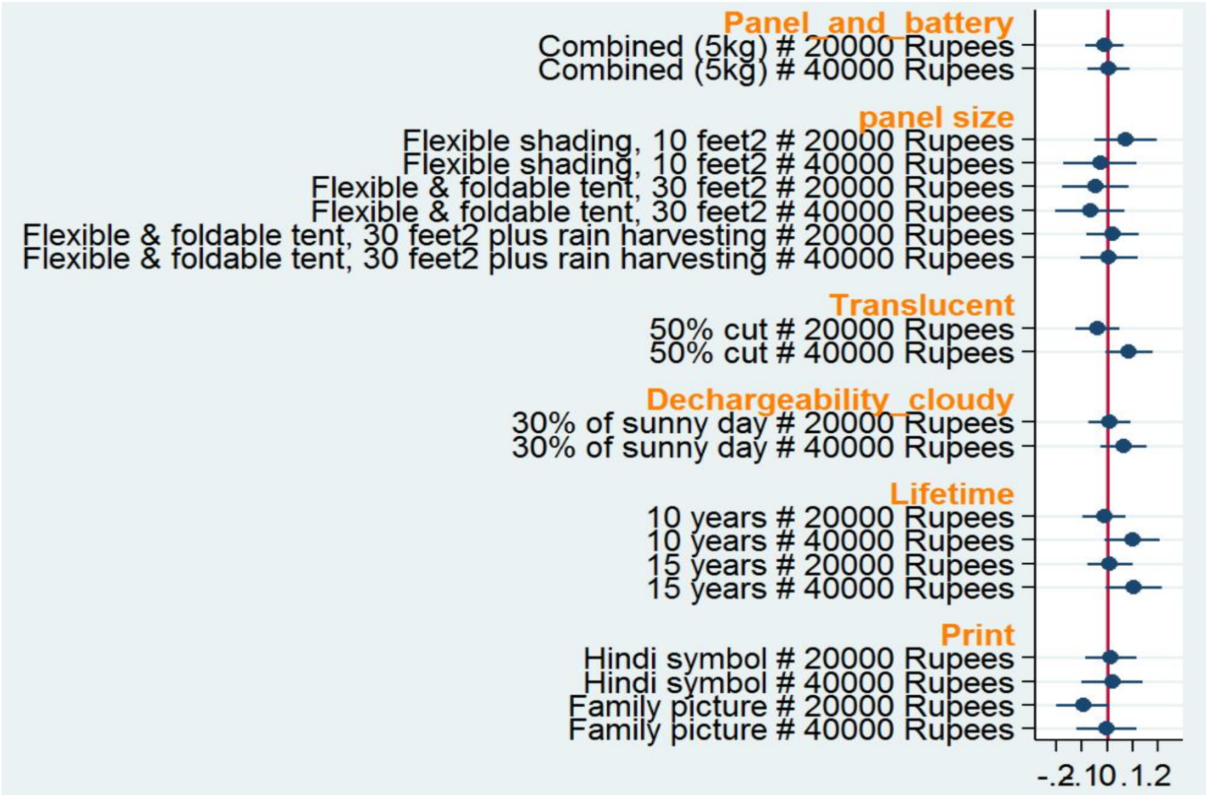


Figure 19: Average causal effects on external choice probability

Control group

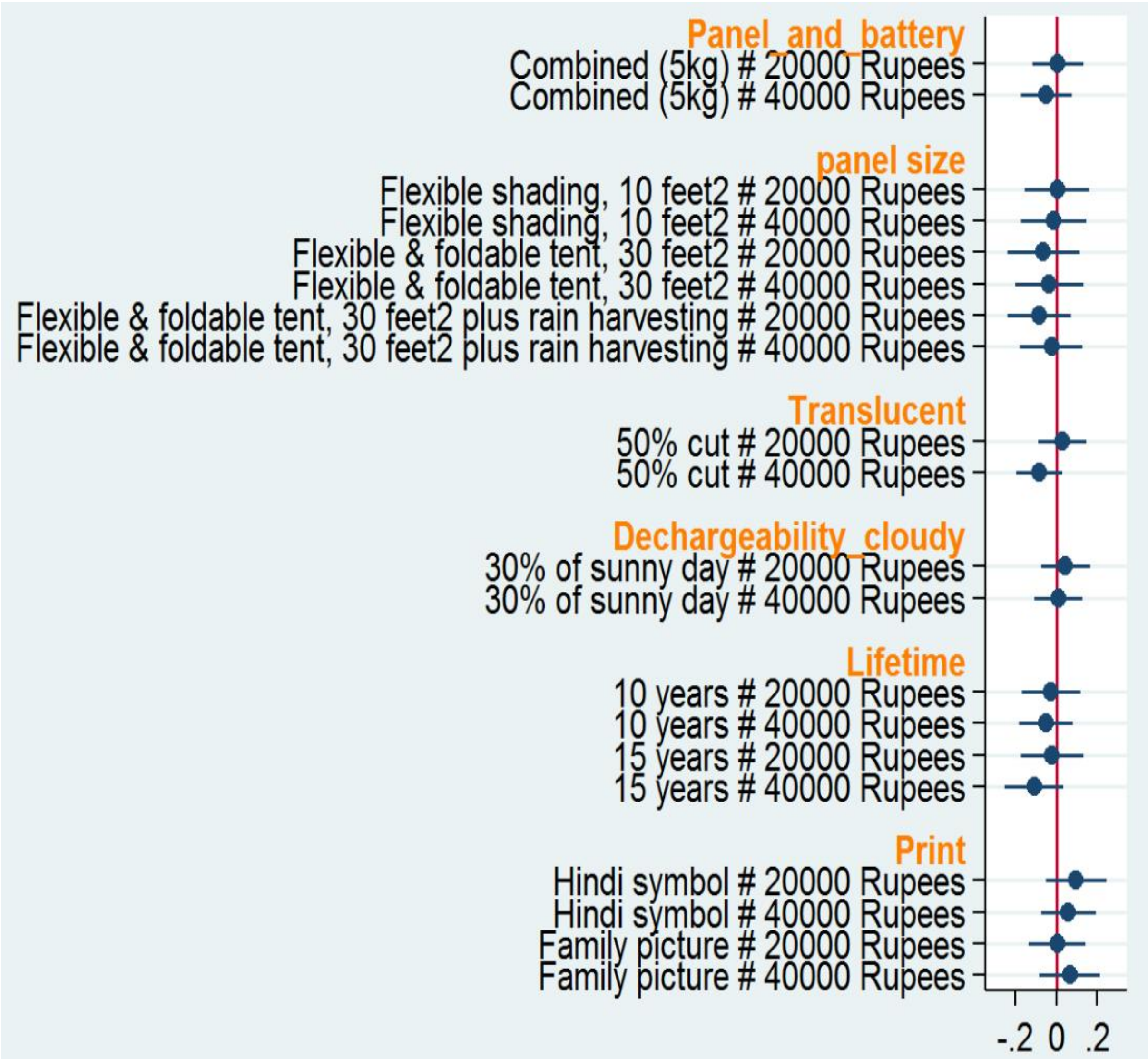


Figure 20: Average causal effects on internal choice probability

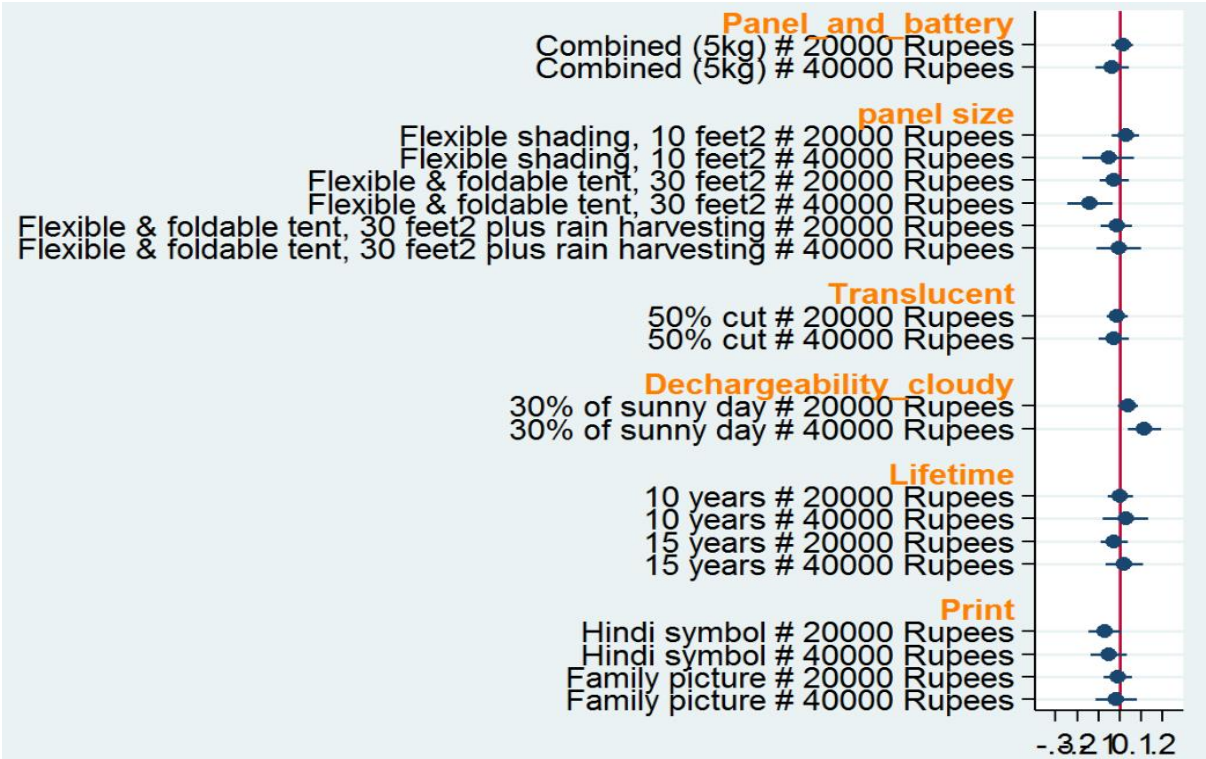


Figure 21: Average causal effects on external choice probability

In the control group, most of the interaction effect among cost and other attributes was negligible, except between 'De-chargeability,' '30% of sunny day,' 'under cloudy weather,' and '40,000 rupees' in external choice probability. This interaction effect was positive and significant, thus implying that respondents wanted to pay more if the system worked under cloudy weather conditions.

The goal of this study was to understand the real situation of non-electrified villages, as well as understanding users' preferences on new features of the future organic solar PV module. The difficulty in the study was that it had adopted organic solar technology which is one of the future technologies. The organic solar PV system is not yet commercialized; therefore, it is challenging to estimate the price, size, heaviness, etc. However, the study took the risk of using the organic solar PV system with a focus mainly on new functions, such as flexibility, portability, and chargeability in bad weather.

Through this study, the researcher was taught one formula;

Technology Database + Social Study = Reverse Innovation

Through this formula, researchers learn that various types of technology are available and that, as humans, we have the option of which technology to use. Every region, even in both developed and developing nations, has suitable technology of its own. A social study can prove “what they really want in the local area”, as well as “what type of technology is preferable for the people and the region”. The answer to reverse innovation that was found through this project was that the real opinions and preferences of the local people need to be reflected in every way possible in the product design.

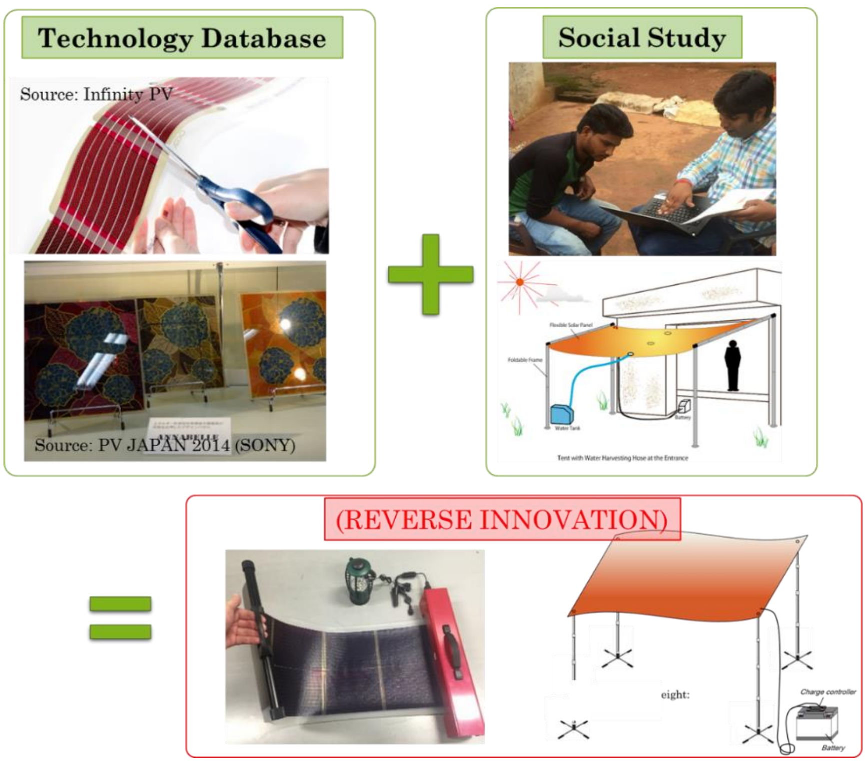


Figure 22: Simplest formula for reverse innovation concept

4.11 Social Trust of Villagers

Another questionnaire survey, together with conjoint analysis, was conducted. This questionnaire focused on social trust. The reason why this questionnaire was enclosed was to observe the relationship between portability (de-mountability) and social confidence. The following four questions (shown in Figures 4.21–4.24) were used to estimate how much the people trusted each other as a group, with this based on work of the World Bank. It was expected that respondents would have some concerns about trouble from burglary due to the panel’s portability. However, contrary to the researcher’s expectation, their trust in each other was extreme. Many villagers even stated that there would be less risk in the village of trouble from burglary even if very nice private SHSs were installed. They were willing to help each other when someone was experiencing trouble (see Figures 4.21–4.24). In the electrified village, some villagers went to the house which had already installed an SHS and used the electricity for free. They shared a cooperative mindset; hence, troubles in the villages were not of much concern to the current study.

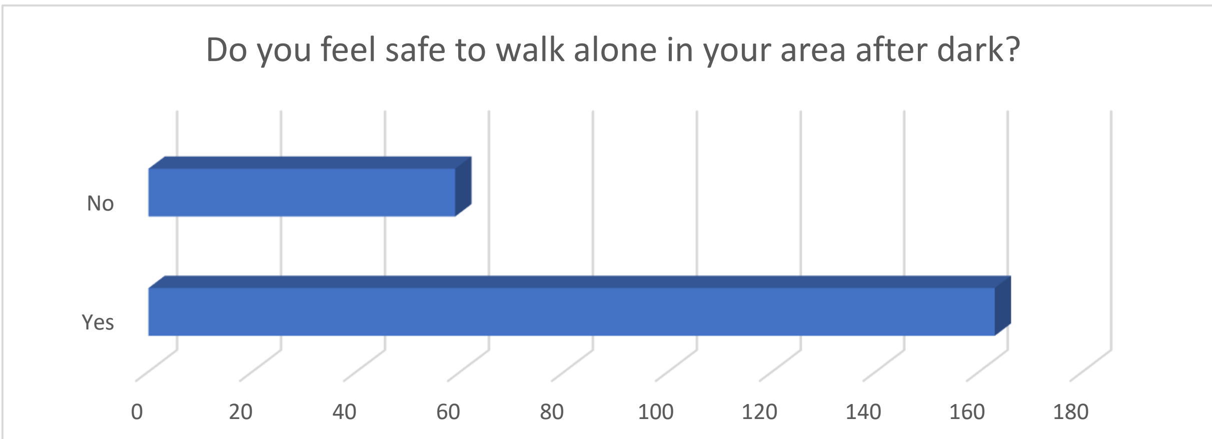


Figure 23: Result of the questionnaire; do you feel safe to walk alone in your area after dark?

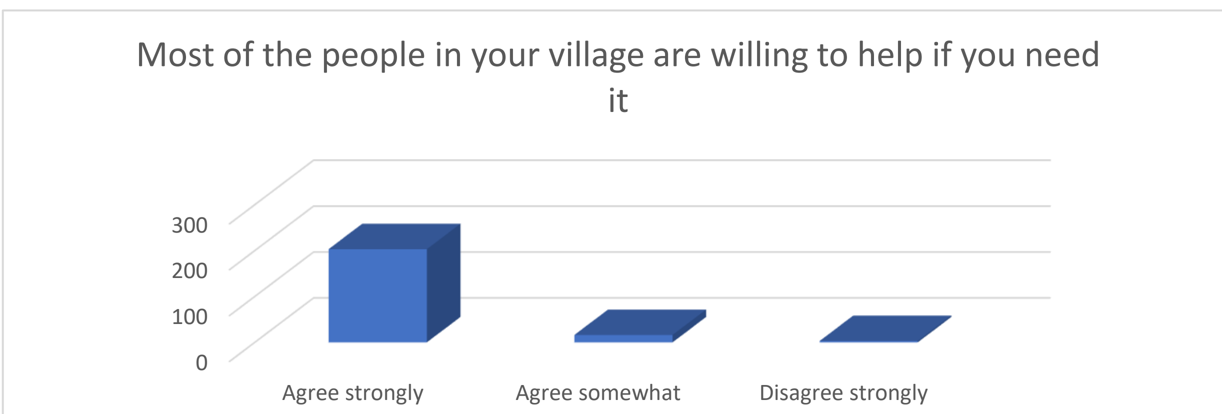


Figure 24: Result of the questionnaire; most people in your village are willing to help if you need it

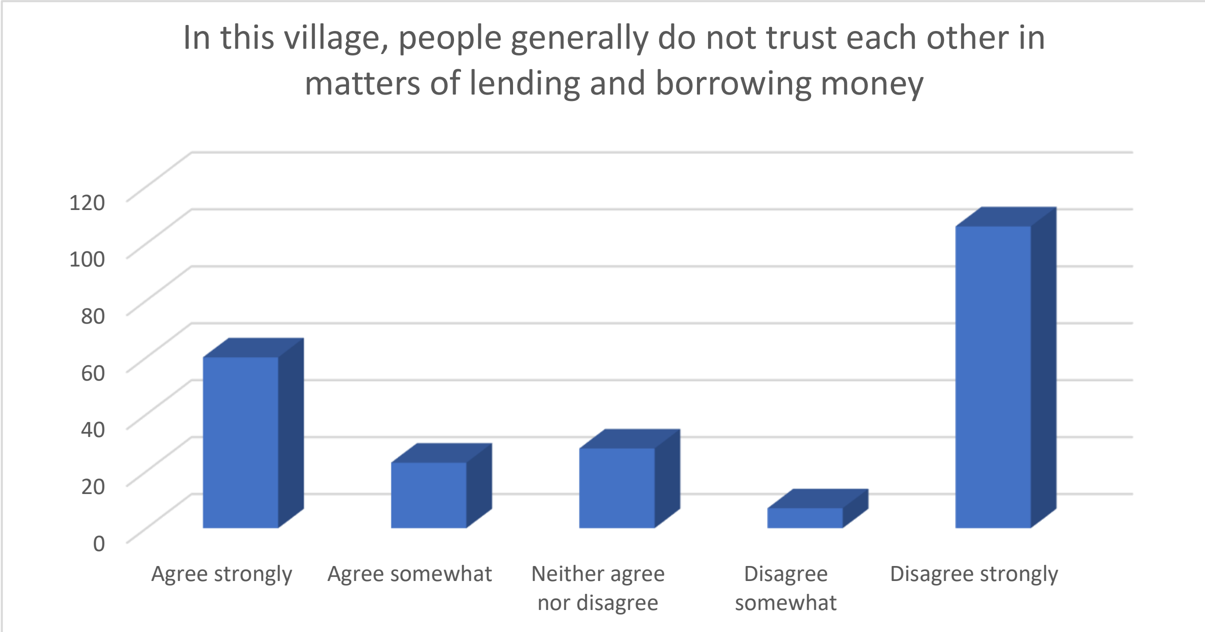


Figure 25: Result of the questionnaire; in this village, people generally do not trust each other in matters of lending and borrowing money

Figure 26: Result of the questionnaire; a lost envelope with your name, in which there is some money, is likely to be returned if someone in your village discovers it.

4.12 Conclusion

The off-grid rural electrification program based on renewable energy is the most effective way to increase energy supply in remote areas of developing countries. Although many such programs have been implemented, the success rate for ensuring long-term sustainability plans is low. Many of these programs fail to adequately address the social and cultural problems of the target communities, resulting in little or no acceptance by users. Similarly, many rural electrification policies have failed to incorporate user needs and perspectives, resulting in policy measures that cannot be addressed.

Rural areas suffer from energy poverty, and lack of human and economic development. In the current study, one of the preferences of choice depends on energy supply, economic viability, rural economic development, residue management, the nature of end-user applications, and government programs and policies. Most respondents preferred the solar PV system that worked under cloudy weather conditions. They disagreed with the appropriate level price of the product. The actual survey was conducted in two different languages (English and Hindi). Meaningful efforts were made to control translation and interpretation errors. However, given the nature and level of the survey, it may be that some questions may not have been managed as expected.

This study has made it possible to follow a flexible policy development model, tailored by different countries to suit different levels of autonomy in dealing with specific alternatives for their own country. The study's results indicate that energy policy development requires the close collaboration of central and state government authorities. Understanding community attitudes and their energy needs, and engaging community involvement in planning and project design have been found to be the cornerstone for achieving long-term sustainability initiatives.

Chapter 5: Conclusion and Policy Recommendations

Energy can be said to be one of the main challenges facing the world today, covering all aspects of our lives. For those living in extreme poverty, the lack of access to modern energy services greatly affects health, limits opportunities, and widens the gap between the rich and the poor. Expanding access to modern energy services is a huge challenge for developing countries, especially in the poorest countries. Improved energy use, especially access to electricity, has a significant impact on education. For example, it reduces the inconvenience of this learning opportunity and allows children to increase their school attendance. They can go to school and other educational activities. Also, due to electrification, rural households receive enough luminescence for study. The family can use television, radio, and information and communications technology (ICT) for educational purposes.

This study assessed the effect on educational outcomes of current energy access in developing countries. It also discussed changes in package size and technological innovation as well as consumers' preferences for the future organic solar PV system. The study accessed a range of currently available energy access data from the MICS database, with data also collected from the field survey in Bangladesh and India. Extensive energy access data were not only crucial for understanding the energy use of developing countries, but also invaluable were the policies and plans being used to address energy poverty issues to strengthen the expansion of modern energy services.

The purpose of this study was to draw attention to energy access beyond traditional electricity supply, especially in poorer developing countries where access is most restricted. The study also raised questions related to the availability of energy access statistics. The study has drawn attention to:

■ Electricity access in the least-developed countries (LDCs) and the effect of grid electrification on school enrollment in the short run as well as the long run.

■ Access to off-grid electricity, specifically the solar home system (SHS) in rural Bangladesh and its impact on educational outcomes.

■ Technical innovation as well as changes in package size of solar home systems (SHSs) in Bangladesh.

■ Evaluating consumers' preferences for organic solar PV systems in remote areas in Chhattisgarh, India.

The main outcomes of this study are as follows:

- ✓ The effect of access to electricity on grade progression is positive and significant. It also has a significant negative effect on grade repetition. The non-attendance rate is higher in non-electrified areas compared to electrified areas. The simulation result showed that access to electricity is positively associated with better grade progression at upper grades.
- ✓ Currently, grid electricity is unable to be connected in some remote areas in Bangladesh. Renewable energy is the only option to ensure good quality lighting for poor people. The study found a positive impact of SHSs on students' performance and school enrollment. The student who has access to an SHS receives better scores compared to those who do not have access to a solar home system (SHS). The impact of SHSs on grade progression is positive and significant.
- ✓ The SHS is, to date, becoming more popular in rural areas in Bangladesh. The SHS program is one of the most successful off-grid programs with the highest installation rates. Grameen Shakti is the pioneer organization that implemented and maintained SHSs from the early 1990s. Today, dramatic changes are being seen in technological innovation and the SHS package. Consumers indicated their preference for the low watt peak solar PV system at a convenient price. The source of imports of the solar PV system has also changed.
- ✓ The study examined consumers' preferences for future organic solar PV systems over conventional solar PV systems in remote areas in India. A randomized conjoint analysis was conducted based on some attributes and levels. In this regard, some possible features were included that related to future organic solar PV systems. The study found that consumers preferred solar PV systems that were active during cloudy or bad weather conditions.

Based on the above findings, the study proposes strategic options to strengthen education and energy policies as follows:

- The Bangladesh government needs to provide special care to students who study in off-grid areas and arrange a soft loan for poor families to enable them to buy renewable energy lighting tools.
- The education policy in Bangladesh needs to be redefined to incorporate the "ensure good quality of lighting for kids study" policy in the National Education Policy. The government should introduce a separate wing in the Education Ministry and provide support to the existing education policy based on field-level research.
- Steps need to be taken to strengthen and simplify the regulatory framework relating to local needs. This would ensure transparency in evaluation and provide accurate information about the facts of electrification in remote areas.
- Integrated, appropriate and convenient solar home systems (SHSs) need to be developed for rural areas, ensure easy access to these systems for poor people.
- Financial incentives and other inducements should be given to entrepreneurs who are willing to invest in future organic solar PV systems.

Policies and national plans must be significantly strengthened to address the impact of energy access on educational outcomes. If countries do not have a clear understanding of energy access, including understanding regional and national trends, rural/urban differences, the range of energy sources, and consumers' preferences for energy access that is commonly used in poor households, this cannot be done effectively. However, existing data sets and reports often provide insufficient information on access to energy and its effect on educational outcomes. It is essential to identify consumers' preferences for renewable energy technology for lighting purposes. This preference can vary from region to region in developing countries. Proper research and field study are needed regarding the choices of local people when undertaking and implementing appropriate policies.

Appendix

Table 21: Transition matrices (age 7 to 8)

	Grade (G)				
	4	**3**	**2**	**1**	**NA**
Treatment Transition Matrix					
P(5|G)	0.909	---	---	---	---
P(4|G)	0.091	0.986	---	---	---
P(3|G)	---	0.014	0.979	---	---
P(2|G)	---	---	0.021	0.899	---
P(1|G)	---	---	---	0.101	0.499
P(NA|NA)	---	---	---	---	0.501
Observation	11	74	378	1163	1239
P(G)	0.004	0.026	0.132	0.406	0.432
Control Transition Matrix					
P(5|G)	1.000	---	---	---	---
P(4|G)	---	0.960	---	---	---
P(3|G)	---	0.040	0.974	---	---
P(2|G)	---	---	0.026	0.945	---
P(1|G)	---	---	---	0.055	0.571
P(NA|NA)	---	---	---	---	0.429
Observation	11	101	499	1212	983
P(G)	0.004	0.036	0.178	0.432	0.350
Treatment–Control Difference					
P(5|G)	−0.091	---	---	---	---
P(4|G)	0.091	0.026	---	---	---
P(3|G)	---	−0.026	0.005	---	---
P(2|G)	---	---	−0.005	−0.046	---
P(1|G)	---	---	---	0.046	−0.072
P(NA|NA)	---	---	---	---	0.072
Observation	22	175	877	2375	2222
P(G)	0.004	0.031	0.155	0.419	0.392
p-value	0.05	0.50	0.73	0.00	0.29

Table 22: Transition matrices (age 8 to 9)

	Grade (G)					
	5	**4**	**3**	**2**	**1**	**NA**
			Treatment Transition Matrix			
P(6|G)	1.000	---	---	---	---	---
P(5|G)	---	0.965	---	---	---	---
P(4|G)	---	0.035	0.981	---	---	---
P(3|G)	---	---	0.019	0.976	---	---
P(2|G)	---	---	---	0.024	0.944	---
P(1|G)	---	---	---	---	0.056	0.486
P(NA|NA)	---	---	---	---	---	0.514
Observation	10	57	268	706	917	683
P(G)	0.004	0.022	0.101	0.267	0.347	0.259
			Control Transition Matrix			
P(6|G)	0.857	---	---	---	---	---
P(5|G)	0.143	0.966	---	---	---	---
P(4|G)	---	0.034	0.989	---	---	---
P(3|G)	---	---	0.011	0.979	---	---
P(2|G)	---	---	---	0.021	0.941	---
P(1|G)	---	---	---	---	0.059	0.544
P(NA|NA)	---	---	---	---	---	0.456
Observation	7	87	349	805	799	434
P(G)	0.003	0.035	0.141	0.324	0.322	0.175
			Treatment–Control Difference			
P(6|G)	0.143	---	---	---	---	---
P(5|G)	−0.143	−0.001	---	---	---	---
P(4|G)	---	0.001	−0.007	---	---	---
P(3|G)	---	---	0.007	−0.003	---	---
P(2|G)	---	---	---	0.003	0.003	---
P(1|G)	---	---	---	---	−0.003	−0.058
P(NA|NA)	---	---	---	---	---	0.058
Observation	17	144	617	1511	1716	1117
P(G)	0.003	0.028	0.120	0.295	0.335	0.218
p-value	0.09	0.96	0.62	0.75	0.46	0.72

Table 23: Transition matrices (age 9 to 10)

	Grade (G)						
	6	**5**	**4**	**3**	**2**	**1**	**NA**
			Treatment Transition Matrix				
P(7|G)	0.769	---	---	---	---	---	---
P(6|G)	0.231	0.967	---	---	---	---	---
P(5|G)	---	0.033	0.990	---	---	---	---
P(4|G)	---	---	0.010	0.981	---	---	---
P(3|G)	---	---	---	0.019	0.982	---	---
P(2|G)	---	---	---	---	0.018	0.948	---
P(1|G)	---	---	---	---	---	0.052	0.305
P(NA|NA)	---	---	---	---	---	---	0.695
Observation	13	61	302	632	876	730	531
P(G)	0.004	0.019	0.096	0.201	0.279	0.232	0.169
			Control Transition Matrix				
P(7|G)	0.913	---	---	---	---	---	---
P(6|G)	0.087	1.000	---	---	---	---	---
P(5|G)	---	---	0.983	---	---	---	---
P(4|G)	---	---	0.017	0.989	---	---	---
P(3|G)	---	---	---	0.011	0.990	---	---
P(2|G)	---	---	---	---	0.010	0.944	---
P(1|G)	---	---	---	---	---	0.056	0.334
P(NA|NA)	---	---	---	---	---	---	0.666
Observation	23	74	401	816	882	540	335
P(G)	0.007	0.024	0.131	0.266	0.287	0.176	0.109
			Treatment–Control Difference				
P(7|G)	−0.144	---	---	---	---	---	---
P(6|G)	0.144	−0.033	---	---	---	---	---
P(5|G)	---	0.033	0.008	---	---	---	---
P(4|G)	---	---	−0.008	−0.008	---	---	---
P(3|G)	---	---	---	0.008	−0.008	---	---
P(2|G)	---	---	---	---	0.008	0.004	---
P(1|G)	---	---	---	---	---	−0.004	−0.029
P(NA|NA)	---	---	---	---	---	---	0.029
Observation	36	135	703	1448	1758	1270	866
P(G)	0.006	0.022	0.113	0.233	0.283	0.204	0.139
p-value	0.65	0.02	0.80	0.09	0.05	0.74	0.42

Table 24: Transition matrices (age 10 to 11)

	Grade (G)							
	7	**6**	**5**	**4**	**3**	**2**	**1**	**NA**
Treatment Transition Matrix								
P(8|G)	1.000	---	---	---	---	---	---	---
P(7|G)	---	0.949	---	---	---	---	---	---
P(6|G)	---	0.051	0.981	---	---	---	---	---
P(5|G)	---	---	0.019	0.983	---	---	---	---
P(4|G)	---	---	---	0.017	0.989	---	---	---
P(3|G)	---	---	---	---	0.011	0.990	---	---
P(2|G)	---	---	---	---	---	0.010	0.953	---
P(1|G)	---	---	---	---	---	---	0.047	0.215
P(NA|NA)	---	---	---	---	---	---	---	0.785
Observation	8	59	160	470	545	488	275	317
P(G)	0.003	0.025	0.069	0.202	0.235	0.210	0.118	0.137
Control Transition Matrix								
P(8|G)	1.000	---	---	---	---	---	---	---
P(7|G)	---	0.939	---	---	---	---	0.018	---
P(6|G)	---	0.061	0.988	---	---	---	0.006	---
P(5|G)	---	---	0.012	0.986	---	---	---	---
P(4|G)	---	---	---	0.014	0.988	---	---	---
P(3|G)	---	---	---	---	0.012	0.988	---	---
P(2|G)	---	---	---	---	---	0.012	0.941	---
P(1|G)	---	---	---	---	---	---	0.036	0.158
P(NA|NA)	---	---	---	---	---	---	---	0.842
Observation	11	99	251	625	575	403	169	171
P(G)	0.005	0.043	0.109	0.271	0.250	0.175	0.073	0.074
Treatment–Control Difference								
P(8|G)	0.000	---	---	---	---	---	---	---
P(7|G)	---	0.010	---	---	---	---	-0.018	---
P(6|G)	---	−0.010	−0.007	---	---	---	-0.006	---
P(5|G)	---	---	0.007	−0.003	---	---	---	---
P(4|G)	---	---	---	0.003	0.001	---	---	---
P(3|G)	---	---	---	---	−0.001	0.002	---	---
P(2|G)	---	---	---	---	---	−0.002	0.012	---
P(1|G)	---	---	---	---	---	---	0.012	0.057
P(NA|NA)	---	---	---	---	---	---	---	−0.057
Observation	19	158	411	1095	1120	891	444	488
P(G)	0.004	0.034	0.089	0.237	0.242	0.193	0.096	0.105
p-value	0.80	0.28	0.90	0.72	0.17	0.58	0.13	0.04

Table 25: Transition matrices (age 11 to 12)

	Grade (G)								
	8	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**NA**
	Treatment Transition Matrix								
P(9|G)	0.909091	---	---	---	---	---	---	---	---
P(8|G)	0.090909	1.0000	---	---	---	---	---	---	---
P(7|G)	---	---	0.968992	---	---	---	---	---	---
P(6|G)	---	---	0.031008	0.982544	---	---	---	---	---
P(5|G)	---	---	---	0.017456	0.981508	---	---	---	---
P(4|G)	---	---	---	---	0.018492	0.977586	---	---	---
P(3|G)	---	---	---	---	---	0.022414	0.976253	---	---
P(2|G)	---	---	---	---	---	---	0.023747	0.92	---
P(1|G)	---	---	---	---	---	---	---	0.08	0.050699
P(NA|NA)	---	---	---	---	---	---	---	---	0.949301
Observation	11	69	258	401	703	580	379	200	572
P(G)	0.003467	0.021746	0.081311	0.126379	0.221557	0.182792	0.119445	0.063032	0.180271
	Control Transition Matrix								
P(9|G)	0.923077	---	---	---	---	---	---	---	---
P(8|G)	0.076923	0.983193	---	---	---	----	---	---	---
P(7|G)	---	0.016807	0.978622	---	---	---	---	---	---
P(6|G)	---	---	0.021378	0.983957	---	---	---	---	---
P(5|G)	---	---	---	0.016043	0.983957	---	---	---	---
P(4|G)	---	---	---	---	0.016043	0.973684	---	---	---
P(3|G)	---	---	---	---	---	0.026316	0.977695	---	---
P(2|G)	---	---	---	---	---	---	0.022305	0.926606	---
P(1|G)	---	---	---	---	---	---	---	0.073394	0.063091
P(NA|NA)	---	---	---	---	---	---	---	---	0.936909
Observation	13	119	421	561	748	494	269	109	317
P(G)	0.004261	0.039004	0.137988	0.183874	0.245166	0.161914	0.088168	0.035726	0.1039
	Treatment–Control Difference								
P(9|G)	−0.01399	---	---	---	---	---	---	---	---
P(8|G)	0.013986	0.016807	---	---	---	---	---	---	---
P(7|G)	---	−0.01681	−0.00963	---	---	---	---	---	---
P(6|G)	---	---	0.00963	−0.00141	---	---	---	---	---
P(5|G)	---	---	---	0.001414	−0.00245	---	---	---	---
P(4|G)	---	---	---	---	0.002449	0.003902	---	---	---
P(3|G)	---	---	---	---	---	−0.0039	−0.00144	---	---
P(2|G)	---	---	---	---	---	---	0.001442	−0.00661	---
P(1|G)	---	---	---	---	---	---	---	0.006606	−0.01239
P(NA|NA)	---	---	---	---	---	---	---	---	0.012392
Observation	24	188	679	962	1451	1074	648	309	889
P(G)	0.003856	0.030206	0.109094	0.154563	0.23313	0.172558	0.104113	0.049647	0.142834
p-value	0.8	0.70	0.01	0.31	0.79	0.89	0.08	0.01	0.04

Table A6: Transition matrices (age 13 to 14)

	Grade (G)										
	10	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**NA**
Treatment Transition Matrix											
P(11|G)	1.000	---	---	---	---	---	---	---	---	---	---
P(10|G)	---	1.000	---	---	---	---	---	---	---	---	---
P(9|G)	---	---	0.995	---	---	---	---	---	---	---	---
P(8|G)	---	---	0.005	0.997	---	---	---	---	---	---	---
P(7|G)	---	---	---	0.003	0.988	---	---	---	---	---	---
P(6|G)	---	---	---	---	0.012	0.976	---	---	---	---	---
P(5|G)	---	---	---	---	---	0.024	0.979	---	---	---	---
P(4|G)	---	---	---	---	---	---	0.021	0.971	---	----	---
P(3|G)	---	---	---	---	---	---	---	0.029	1.000	---	---
P(2|G)	---	---	---	---	---	---	---	---	---	1.000	---
P(1|G)	---	---	---	---	---	---	---	---	---	---	0.002
P(NA|NA)	---	---	---	---	---	---	---	---	---	---	0.998
Observation	1	53	190	346	344	209	194	105	61	21	657
P(G)	0.0005	0.0243	0.0871	0.1586	0.1577	0.0958	0.0890	0.0481	0.0280	0.0096	0.3012
Control Transition Matrix											
P(11|G)	0.900	---	---	---	---	---	---	---	---	---	---
P(10|G)	0.100	0.980	---	---	---	---	---	---	---	---	---
P(9|G)	---	0.020	0.992	---	---	---	---	---	---	---	---
P(8|G)	---	---	0.008	0.991	---	---	---	---	---	---	---
P(7|G)	---	---	---	0.009	0.988	---	---	---	---	---	---
P(6|G)	---	---	---	---	0.012	0.988	---	---	---	---	---
P(5|G)	---	---	---	---	---	0.012	0.959	---	---	---	---
P(4|G)	---	---	---	---	---	---	0.041	0.972	---	---	---
P(3|G)	---	---	---	---	---	---	---	0.028	0.967	---	---
P(2|G)	---	---	---	---	---	---	---	---	0.033	0.905	---
P(1|G)	---	---	---	---	---	---	---	---	---	0.095	0.002
P(NA|NA)	---	---	---	---	---	---	---	---	---	---	0.998
Observation	10	98	368	530	431	243	148	71	30	21	478
P(G)	0.0041	0.0404	0.1516	0.2183	0.1775	0.1001	0.0610	0.0292	0.0124	0.0086	0.1969
Treatment–Control Difference											
P(11|G)	0.100	---	---	---	---	---	---	---	---	---	---
P(10|G)	−0.100	0.020	---	---	---	---	---	---	---	---	---
P(9|G)	---	−0.020	0.003	---	---	---	---	---	---	---	---
P(8|G)	---	---	−0.003	0.007	---	---	---	---	---	---	---
P(7|G)	---	---	---	−0.007	0.000	---	---	---	---	---	---
P(6|G)	---	---	---	---	0.000	−0.012	---	---	---	---	---
P(5|G)	---	---	---	---	---	0.012	0.020	---	---	---	---
P(4|G)	---	---	---	---	---	---	-0.020	0.000	---	---	---
P(3|G)	---	---	---	---	---	---	---	0.000	0.033	---	---
P(2|G)	---	---	---	---	---	---	---	---	−0.033	0.095	---
P(1|G)	---	---	---	---	---	---	---	---	---	−0.095	−0.001
P(NA|NA)	---	---	---	---	---	---	---	---	---	---	0.001
Observation	11	151	558	876	775	452	342	176	91	42	1135
P(G)	0.0024	0.0328	0.1211	0.1901	0.1681	0.0981	0.0742	0.0382	0.0197	0.0091	0.2463
p-value	0.90	0.04	0.06	0.25	0.09	0.80	0.41	0.99	0.01	0.39	0.50

Table 26: Transition matrices (age 14 to 15)

	Grade(G)											
	11	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**NA**
Treatment Transition Matrix												
P(12|G)	1.000	---	---	---	---	---	---	---	---	---	---	---
P(11|G)	---	1.000	---	---	---	---	---	---	---	---	---	---
P(10|G)	---	---	0.974	---	---	---	---	---	---	---	---	---
P(9|G)	---	---	0.026	0.988	---	---	---	---	---	---	---	---
P(8|G)	---	---	---	0.012	1.000	---	---	---	---	---	---	---
P(7|G)	---	---	---	---	---	0.990	---	---	---	---	---	---
P(6|G)	---	---	---	---	---	0.010	0.955	---	---	---	---	---
P(5|G)	---	---	---	---	---	---	0.045	0.985	---	---	---	---
P(4|G)	---	---	---	---	---	---	---	0.015	0.956	---	---	---
P(3|G)	---	---	---	---	---	---	---	---	0.044	0.957	---	---
P(2|G)	---	---	---	---	---	---	---	---	---	0.043	0.846	---
P(1|G)	---	---	---	---	---	---	---	---	---	---	0.154	0.001
P(NA|NA	---	---	---	---	---	---	---	---	---	---	---	0.999
Observatio	1	11	151	330	288	195	110	65	45	23	13	896
P(G)	0.0004	0.0051	0.0709	0.1550	0.1353	0.0916	0.0516	0.0305	0.0211	0.0108	0.0061	0.4210
Control Transition Matrix												
P(12|G)	1.000	---	---	---	---	---	---	---	---	---	---	---
P(11|G)	---	0.982	---	---	---	---	---	---	---	---	---	---
P(10|G)	---	0.018	0.990	---	---	---	---	---	---	---	---	---
P(9|G)	---	---	0.010	0.994	---	---	---	---	---	---	---	---
P(8|G)	---	---	---	0.006	0.995	---	---	---	---	---	---	---
P(7|G)	---	---	---	---	0.005	0.986	---	---	---	---	---	---
P(6|G)	---	---	---	---	---	0.014	0.981	---	---	---	---	---
P(5|G)	---	---	---	---	---	---	0.019	0.971	---	---	---	---
P(4|G)	---	---	---	---	---	---	---	0.029	1.000	---	---	---
P(3|G)	---	---	---	---	---	---	---	---	---	0.944	---	---
P(2|G)	---	---	---	---	---	---	---	---	---	0.056	1.000	---
P(1|G)	---	---	---	---	---	---	---	---	---	---	---	0.006
P(NA|NA	---	---	---	---	---	---	---	---	---	---	---	0.994
Observatio	10	55	303	526	409	222	108	70	31	18	5	698
P(G)	0.0040	0.0224	0.1234	0.2142	0.1665	0.0904	0.0439	0.0285	0.0126	0.0073	0.0020	0.2843
Treatment-Control Differences												
P(12|G)	0.000	---	---	---	---	---	---	---	---	---	---	---
P(11|G)	---	0.018	---	---	---	---	---	---	---	---	---	---
P(10|G)	---	-0.018	-0.017	---	---	---	---	---	---	---	---	---
P(9|G)	---	---	0.017	-0.006	---	---	---	---	---	---	---	---
P(8|G)	---	---	---	0.006	0.005	---	---	---	---	---	---	---
P(7|G)	---	---	---	---	-0.005	0.003	---	---	---	---	---	---
P(6|G)	---	---	---	---	---	-0.003	-0.027	---	---	---	---	---
P(5|G)	---	---	---	---	---	---	0.027	0.013	---	---	---	---
P(4|G)	---	---	---	---	---	---	---	-0.013	-0.044	---	---	---
P(3|G)	---	---	---	---	---	---	---	---	0.044	0.0120	---	---
P(2|G)	---	---	---	---	---	---	---	---	---	-	-0.154	---
P(1|G)	---	---	---	---	---	---	---	---	---	---	0.154	-0.005
P(NA|NA	---	---	---	---	---	---	---	---	---	---	---	0.005
Observati	10	66	454	856	697	417	218	135	76	41	18	1594
P(G)	0.0021	0.0144	0.0990	0.1867	0.1520	0.0909	0.0475	0.0294	0.0165	0.0089	0.0039	0.3478
p-value	0.85	0.43	0.03	0.24	0.02	0.86	0.91	0.33	0.13	0.66	0.03	0.33

NA = Non-attendance

Table 27: Grade transition in un-electrified areas (treatment)

	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Grade 6	Grade 7	Grade 8	Grade 9	Grade 10	Grade 11	Grade 12	NA
Age 5	690	43											9267
Age 6	2072	355	40										7533
Age 7	3270	1662	344	40									4685
Age 8	2669	2973	1631	343	36								2348
Age 9	1290	2592	2932	1613	331	36							1207
Age 10	435	1270	2600	2893	1608	328	28						839
Age 11	200	428	1286	2621	2874	1594	311	28					659
Age 12	49	195	446	1305	2622	2873	1545	314	25				625
Age 13	11	48	199	443	1372	2564	2867	1537	314	25			619
Age 14	1	11	54	203	467	1369	2543	2867	1529	314	25		618
Age 15	1	1	12	55	221	459	1355	2577	2873	1489	314	25	617

Table 28: Grade transition in electrified areas (control)

	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Grade 6	Grade 7	Grade 8	Grade 9	Grade 10	Grade 11	Grade 12	NA
Age 5	733	40											9227
Age 6	2368	439	34										7159
Age 7	3851	1984	422	34									3710
Age 8	2330	3690	1949	405	34								1592
Age 9	1003	2271	3634	1941	396	29							727
Age 10	299	970	2288	3628	1907	398	26						484
Age 11	87	300	986	2312	3599	1908	374	26					407
Age 12	32	88	319	997	2333	3582	1874	370	24				382
Age 13	12	31	94	325	1007	2373	3535	1860	369	22			372
Age 14	2	12	33	104	324	1022	2379	3517	1852	364	20		371
Age 15	2	3	12	36	108	332	1020	2387	3515	1840	357	20	369

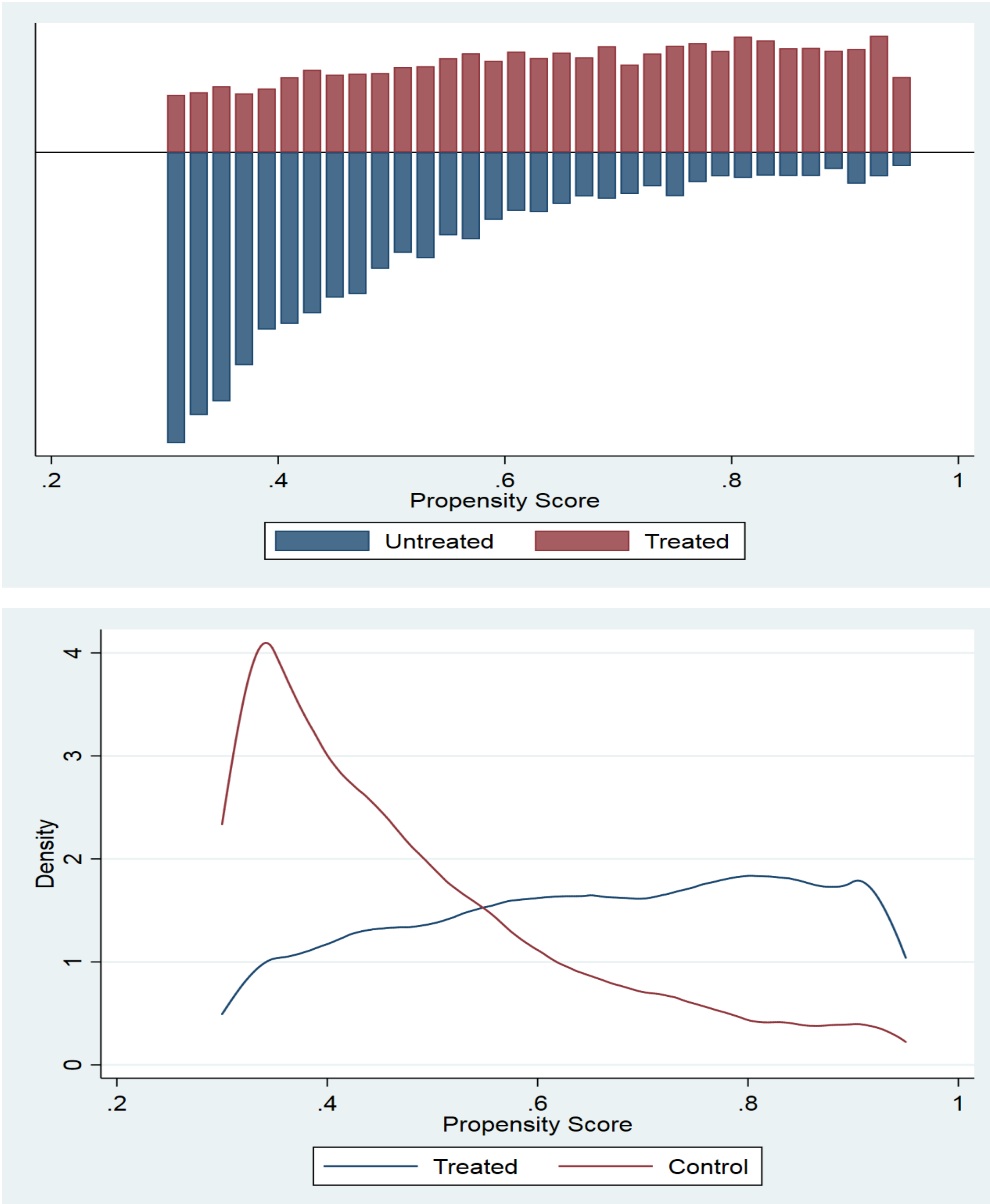


Figure 27: Propensity score distribution for purpose of common support

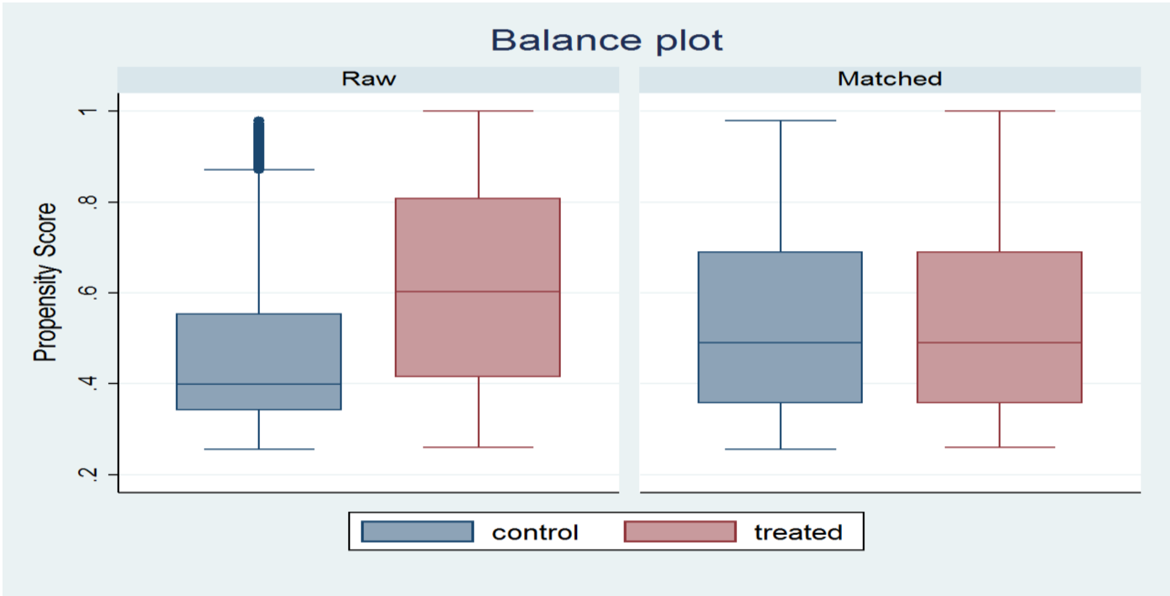


Figure 28: Covariate balancing test

Attributes and Levels (Electricity Use)

No.	Attributes	Level 1	Level 2	Level 3
1	उपलCधता/Availabilty	हर रोज/Everyday	केवल अPछे fदन में/Only fine days	
2	लाईटींग/Lighting	2 LED	4 LED	8 LED
3	मोबाईल चाftZग (फूल चाftZग)/Mobile charger (full charge)	उपलCध नही/Not available	१ मोबाईल हर रोज/1 phone/day	३ मोबाईल हर रोज/3 phones/day
4	टीवी और रेडियो/TV and radio	उपलCध नही/Not available	३ घंटा/दिन/ 3 hours/day	६ घंटा/दिन/ 6 hours/day
5	टेबल फेन/Table fan	उपलCध नही/ Not available	३ घंटा/दिन/ 3 hours/day	
6	lfoZl अवधि/Service duration	५ साल/5 years	१० साल/10 years	१५ साल/15 years
7	कीमत (एक ही बार)/Price (one time payment)	10000 Rupees	20000 Rupees	40000 Rupees

Figure 29: Attributes and levels of electricity use in pilot survey

Attributes and Levels (Product Design)

No.	Attributes	Level 1	Level 2	Level 3
1	लगाने व िनकालने की सुिवधा Detachability	नकालने की सुिवधा Detachable (30kg)	िनकालने की सुिवधा व दुसरी जगह ले जाने की सुिवधा Detachable and portable (10kg)	
2	पेनल लगाने की जगह व उपयोग Mounting location and use	छत के ऊपर Rooftop	छजने पर Shading eaves	िखडकी के गलास पर Window glasses
3	अच्छे मौसम में फुल चािजेंग में लगने वाला समय Time for full charge in fine weather	4 hours/ घंटा	6 hours/घंटा	8 hours/घंटा
4	बदली मौसम में चािजेंग में लगने वाला समय Chargeability in cloudy weather	50% of fine weather केवल अच्छे दिन में	30% of fine weather केवल अच्छे दिन में	10% of fine weather केवल अच्छे दिन में
5	जीवनकाल Lifetime	5 years	10 years	
6	कीमत (एक बार भुगतान) Price (one time payment)	10000 Rupees	20000 Rupees	40000 Rupees

Figure 31: Attributes and levels of product design in pilot survey

Attributes and Levels (New Product Design 1)

No.	Attributes	Level 1	Level 2	Level 3
1	**System design of panel and battery**	Separated, fixed panel and heavy battery (80kg)	Combined, panel and light battery (totally 3kg)	
2	**Panel size and feature**	Hard, conventional (1 feet2)	Flexible, good for shading eave (10 feet2)	Flexible, good for tent (30 feet2) plus rain harvesting
3	**Translucent**	100% cut (such as black sheet)	50% cut	
4	**Chargeability in cloudy weather**	0 % (same as conventional)	Yes (30% of cloudy day)	
5	**Lifetime**	5 years	10 years	15 years
6	**Price (one time payment)**	10000 Rupees	20000 Rupees	40000 Rupees
7	**Print design on the panel surface**	Nothing	Hindi symbol	Family picture

Figure 32: Attributes and levels of new product design 1 in pilot survey

Attributes and Levels (New Product Design 2)

No.	**Attributes**	**Level 1**	**Level 2**	**Level 3**	**Level 4**
1	**System design of panel and battery**	Separated, fixed panel and heavy battery (30kg)	Combined, panel and light battery (totally 5kg)		
2	**Panel size and feature**	Hard, conventional (1 feet2)	Flexible panel, good for shading eave extended from roof (10 feet2)	Flexible panel & foladable frame, good for tent (30 feet2)	Flexible panel & foladable frame, good for tent (30 feet2) plus rain water harvesting
3	**Translucent**	100% cut (such as black sheet)	50% cut (such as sun glasses)		
4	**Chargeability in cloudy weather**	0 % (same as conventional)	Yes (30% of sunny day)		
5	**Lifetime**	5 years	10 years	15 years	
6	**Price (one time payment)**	10000 Rupees	20000 Rupees	40000 Rupees	
7	**Print design on the panel surface**	Nothing	Hindi symbol	Family picture	

Figure A6: Attributes and levels of new product design 2 in main survey

The 1st trial		Choice ID 78	Choice ID 544	
		Choice A	Choice B	Choice C
Attribute 1	टेबल फेन/Table fan	उपलCध नही/ Not available	उपलCध नही/ Not available	
Attribute 2	टीवी और रेfडयो/TV and radio	३ घंटा/fदन/ 3 hours/day	उपलCध नही/Not available	
Attribute 3	lfoZl अवfध/Service duration	१० साल/10 years	१० साल/10 years	
Attribute 4	उपलCधता/Availabilty	हर रोज/Everyday	केवल अPछे fदन में/Only fine days	नही चाि्हये / Do not want
Attribute 5	मोबाईल चाftZग (फुल चाftZग)/Mobile charger (full charge)	१ मोबाईल हर रोज/1 phone/day	१ मोबाईल हर रोज/1 phone/day	
Attribute 6	कीमत (एक ही बार)/Price (one time payment)	40000 Rupees	10000 Rupees	
Attribute 7	लाईटींग/Lighting	2 LED	2 LED	
	Your Ranking ==>			

Figure 33: Example of set of choices for electricity use in pilot survey

The 2nd trial		Choice ID 857	Choice ID 567	
		Choice A	Choice B	Choice C
Attribute 1	System design of panel and battery	Combined, panel and light battery (totally 5kg)	Combined, panel and light battery (totally 5kg)	
Attribute 2	Translucent	50% cut (such as sun glasses)	100% cut (such as black sheet)	
Attribute 3	Panel size and feature	Flexible panel & foladable frame, good for tent (30 feet2) plus rain water	Flexible panel, good for shading eave extended from roof (10 feet2)	
Attribute 4	Lifetime	15 years	15 years	नही चाि्हये / Do not want
Attribute 5	Print design on the panel surface	Hindi symbol	Family picture	
Attribute 6	Chargeability in cloudy weather	Yes (30% of sunny day)	0 % (same as conventional)	
Attribute 7	Price (one time payment)	10000 Rupees	40000 Rupees	
	Your Ranking ==>			

Figure 34: Example of set of choices for new product design 2 in main survey

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