FINAL REPORT

Impact Assessment of Solar Mini-grid, Solar Irrigation and Improved Cooking Stove Projects of IDCOL

MONZUR HOSSAIN, PhD
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Submitted to

Infrastructure Development Company Limited (IDCOL)

June 30, 2020

Bangladesh Institute of Development Studies (BIDS)

E-17 Agargaon, Sher-e-Bangla Nagar, Dhaka-1207, Bangladesh

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Dr. Monzur Hossain

Senior Research Fellow and Study Director

Bangladesh Institute of Development Studies (BIDS)

PART-I: Impact Assessment of Solar Mini-Grid Program of IDCOL

PART-II: Impact Assessment of Solar Irrigation Program of IDCOL

PART-III: Impact Assessment of Improved Cook Stove (ICS) Program of IDCOL

EXECUTIVE SUMMARY

PART-I: Solar Mini-grid Program

One of the major pathways towards sustained and higher economic growth is through providing access to electricity in rural poor population excluded from grid-electricity connection due to geographical barriers. Since 2010, the Infrastructure Development Company Limited (IDCOL) has been financing implementation of solar mini grid (SMG) projects as part of scaling up solar electricity in order to meet the higher electricity needs of the market, small enterprises and households. IDCOL has so far financed 23 solar mini-grid projects in rural remote areas. The objective of this study is to estimate the socio-economic benefits of solar mini-grid project of IDCOL. The study analyzes the impact of SMG adoption on households' income, asset, educational and social outcomes using primary survey data of 2000 households. Access to SMG not only provided better electricity in terms of reliability and lighting coverage compared to IDCOL's other renewable projects (e.g. Solar Home System); it also makes a positive impact on children's education, income generation, improvement of quality of life, safety and security.

Our findings regarding the impact of SMG adoption on key welfare outcomes show that, on average, per capita income, expenditures and asset have significantly increased for the treatment group compared to the control group. We find a statistically significant increase of total study time per day by 12 minutes which is further supported by our regression results of a significant increase of total and boys' study time by about 25% in the treatment group. Access to SMG electricity significantly increases per capita income, particularly per-capita non-farm income, which is about 27%. Moreover, we find that access to solar mini-grid electricity increases all types of consumption (food and non-food) as well as increase in assets. Hence, solar mini-grid electricity enhances welfare of the households.

One important benefit of solar electricity is that it provides access to environment-friendly clean energy. We estimate that SMG electricity saves consumption of Kerosene worth Tk.136 (price of 2 liter) for each of the beneficiary households per month. Currently, 23 mini-grid projects are operational which connected 12,298 customers till July 2019. However, tariff for SMG electricity is reasonably high and initiatives should be taken to reduce this burden of electricity cost for sustainable welfare generation of the poorer households. Low cost financing solution through initiating green bonds and other instruments with proper policies of the government might make SMG electricity affordable to the poor.

PART-II: Solar Irrigation Program

Solar-powered irrigation systems are innovative and environment friendly solutions for agro-based economies like Bangladesh with reduction in fossil fuel dependency and grid electricity demand during irrigation seasons. Since 1971, Bangladesh has been able to increase its rice production three-fold, mostly due to mechanization in agriculture, conducive policy environment and increasing irrigation facilities. In recent times, the country has stepped into solar-powered irrigation technology which opens up a new avenue in agricultural production with increased efficiency and reliability in irrigation, enhanced crop production and food security to a greater extent. The Infrastructure Development Company Limited (IDCOL) has approved 1,429 solar irrigation pumps up to December 2018 and has set up a target of installing 50,000 solar irrigation pumps by 2025. The objective of this impact assessment study is to estimate the socio-economic benefits of solar irrigation compared to the non-solar based irrigation used in selected locations.

Our findings regarding the impact of solar irrigation show that farmers who are using solar irrigation (treatment) had harvested in significantly higher number of plots (3 vs 2.7 plots in Kharif-2 and 3.17 vs 2.8 plots in Rabi) and higher areas of land (1.35 vs 1.26 acre in Kharif-2 and 1.4 vs 1.3 acre in Rabi) compared to non-solar irrigation user group. We further looked at the impacts of solar irrigation on adequacy of water and cost of production. Our regression results suggest that the solar-powered irrigation provides greater access and reliability to meet the adequacy of water used for irrigation more efficiently. It is also found that solar irrigation reduces the cost of production marginally though the reduction of cost appears to be insignificant.

Based on diesel use per acre of land, we have estimated carbon emission by different types of pumps based on their longevity. Our estimation results suggest that with the increase in age of the diesel pumps, their carbon emission also increases. On average the diesel pumps emit 7.5 Kg Carbon Dioxide among the three seasons amassing 22.3484 Kg per acre over the course of a year.

Overall, solar-powered irrigation provides opportunity to irrigate a higher amount of land due to its beneficial aspects such as low cost, low wastage of water, and reliability, and consequently it also contributes to a higher amount of return from harvesting. In addition, it saves carbon emission and therefore contributes to reducing air pollution. During off-season, solar electricity generated from the solar irrigation projects is used for various other purposes. Therefore, to harness greater benefit for the farmers; more awareness building efforts are required in this regard along with dynamic price adjustments in irrigation related equipment as well. Environmental aspects, particularly use of deep surface water has to be contained. Finally, as the results are drawn from a cross-section survey data, more rigorous analysis could be done by making a panel of baseline and follow up data.

PART-III Improved Cooking Stoves Program

The objective of this study is to assess the socio-economic benefits of Improved Cook Stove (ICS) program of IDCOL. For this purpose, a total of 2000 households have been systematically randomly selected and surveyed. Out of the total sample size; 1000 households were ICS adopted households (i.e. treatment) and the remaining 1000 households were non-adopter (i.e. control) households. Several descriptive, statistical, and econometric methods have been used to process various sets of data and to examine the study objectives with special focus on understanding the socio-economic benefits of ICS on adopted (treatment) households compared to the non-adopted (control) households. The methods include analyses using simple t-statistics with ICS user and non-user in the same village and non-user in control villages; ordinary least square (OLS) and instrumental variable (IV) regression models to understand the socio-economic (e.g. fuel consumption, income, health etc.) impacts of ICS on household welfare.

The results depict that the total time for cooking meal is significantly (i.e. 156.24 minutes) lower for ICS (treatment) households compared to non-ICS (control) households (i.e. 174.71 minutes) exhibiting about 20 minutes **time savings** of the ICS adopters. The findings further reveal that around 9.00 minutes per week are required for preparing the stove before using and cleaning the stove after cooking which is significantly higher than that of the treatment households which needs around 7.59 minutes. The results indicate that ICS decreases time spent on fuel collection/purchase significantly and saves time.

On average, the respondents (i.e. ICS and non-ICS adopters) reportedly are found to use firewood/twigs as their primary fuel for cooking and parboiling purposes. The lasting of the fuel in terms of number of days exhibits an interesting pattern in terms of **fuel efficiency**. On average, fuel lasts around 69.90 days for the ICS (treatment) households than that of around 49.31 days lasting among the non-ICS (control) households with the difference being statistically significant. This might also indicate the two groups who do not buy the same amount of fuels. The total amount of costs incurred for acquiring fuels further revealed the **cost efficiency** pattern of the treatment (ICS) households. The survey findings show that the treatment group incurred around Tk. 389.31 which is significantly lower than the control group that stands at Tk. 463.88. ICS adopters are less exposed to CO emissions due to less smoke generation (0.70 vs. 0.72; based on PM2.5 / PM10 ratio).

To assess the impact of ICS adoption on various aspects, we run several regressions. The results suggest that ICS adoption reduces cooking time about 16 minutes a day and also fuel collection time by 15 minutes a month. Though saved time due to ICS use appears to be very negligible, this is statistically significant. Regression results also show that ICS user women's time use has significantly increased, which is expected. Therefore, it may be concluded that ICS adoption can save time compared to adoption of traditional stove users, which they can utilize for other activities e.g. taking care of children, helping in children's study/homework, watching television, socializing and visiting neighbors, friends, relatives, entertaining guests, taking rest including wage/salaried work and IGAs.

In sum, though ICS adoption brought some positive benefits to user households, still a large section of households use both traditional and ICS simultaneously. Use of both types of stoves affected the positive benefits of ICS. Some negative aspects of ICS were also reported by the respondents which need to be addressed. Further improvement of ICS addressing households concern is expected to generate higher benefits of ICS. More awareness building programs are also needed to popularize ICS in Bangladesh.

FINAL REPORT-PART I

Impact Assessment of Solar Mini-grid Project of IDCOL

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SUBMITTED TO:

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EXECUTIVE SUMMARY

One of the major pathways towards sustained and higher economic growth is through providing access to electricity in rural poor population excluded from grid-electricity connection due to geographical barriers. Since 2010, the Infrastructure Development Company Limited (IDCOL) is financing implementation of solar mini grid (SMG) projects as part of scaling up solar electricity in order to meet the higher electricity needs of the market, small enterprises and households. IDCOL has so far financed 23 solar mini-grid projects in rural remote areas. The objective of this study is to estimate the socio-economic benefits of solar mini-grid project of IDCOL. The study analyzes the impact of SMG adoption on households' income, asset, educational and social outcomes using primary survey data of 2000 households. Access to SMG not only provided better electricity in terms of reliability and lighting coverage compared to IDCOL's other renewable projects (e.g. Solar Home System); it also makes a positive impact on children's education, income generation, improvement of quality of life, safety and security.

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CHAPTER 1: INTRODUCTION

Bangladesh has been maintaining a sustained and higher economic growth over the last few years with more than 7 percent in recent years. As an inevitable component of growth, there has been an enormous demand for electricity along with other natural resources in the industrial sector and daily consumption in the households. The peak electricity demand in the country is more than 8000 MW while the available generation capacity is at best 6400 MW resulting the nationwide rationing of the electricity supply. Natural gas is the primary fuel for more than 70% of power generation and it is in short supply too. Renewable energy (RE) currently constitutes less than 1% of total power generation in the country. While the service disruption has been widespread, it is the rural areas that face the major share of load-shedding. Moreover, grid does not seem to be a viable option in many pockets of remote and rural areas in the foreseeable future.

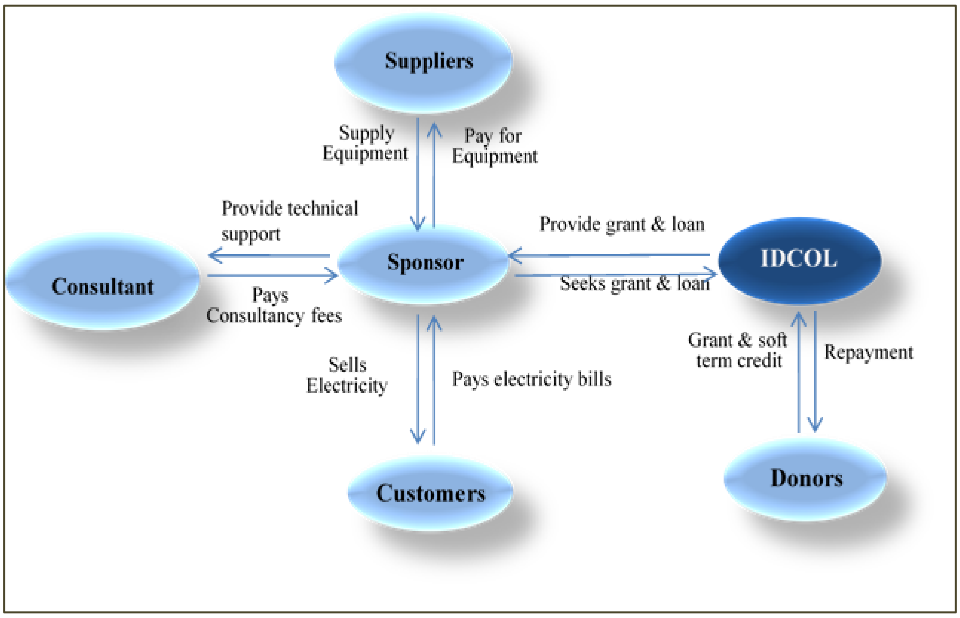
Recognizing the challenges, the Government of Bangladesh (GOB) has adopted multi-pronged energy strategy to meet a set of goals (articulated as vision 2021), most important of which is to ensure universal access by the year 2021 with improved reliability and quality. Though the renewable energy policy (2008) of GOB laid out the target of meeting 5% of total power demand from renewable energy sources by 2015 and 10% by 2020, the target appears to be unrealistic.

However, various RE programs and projects are ongoing mostly from public initiatives. The most successful renewable energy program has been the solar home system (SHS), administered by Infrastructure Development Company Limited (IDCOL) with funding from the World Bank under the RERED project and other donors. The SHS program has installed about 4.13 million SHS to households in rural Bangladesh as of 2018. However, SHS is not adequate when the electricity demand is moderately high, particularly for rural enterprises or market. To address this issue, IDCOL started implementing mini grid projects since 2011 as part of scaling up solar electricity in order to meet the higher electricity needs of the market and small enterprises. Private operators selected by IDCOL would be investing in mini grid in selected location through agreements with the interested customer.

1.1 Solar Mini-grid projects of IDCOL

IDCOL has so far financed 23 solar mini-grid projects in rural remote areas and sets a target to finance 200 solar mini-grid projects by 2025. The modality of a typical solar mini-grid project is shown diagrammatically below (Figure 1.1).

Figure 1.1: Program structure of IDCOL Solar mini-grid projects



Source: IDCOL.

Average project cost of a 250 kWp solar mini-grid is about USD1,187,500. The solar mini-grid projects are financed based on debt, grant and equity ratio of 30%:50%:20%. The terms and conditions of loan are given in Table 1.1:

Table 1.1: Financing terms of loan under solar mini-grid project

Interest rate	6%
Tenor	10 years
Grace period	2 years
Payment frequency	quarterly
Payment Type	annuity
Number of installments	32
Security	Bank guarantee or land mortgage

Source: IDCOL

The security package under the financing involves fixed and floating charge on all fixed and floating assets, assignment of lease benefit/mortgage of project land in favor of IDCOL, personal guarantee of the shareholders of the borrower/members of the executive committee, post-dated cheques, demand promissory note, bank guarantee or land mortgage in equivalent value of the loan amount etc. The grant support extended by IDCOL is intended to enable the sponsor to offer affordable tariff to the rural customers. The electricity tariff under solar mini-grid project is Tk.30~32 per kWh (US$0.37).[1] Though tariff is much higher than the rate offered by the government utilities in grid areas, it is the alternative solution for the people living in those areas considering their available alternatives e.g. generation from DG-genset, solar home system or kerosene lamps etc.

The 50% grant support reduces the initial capital cost of the project which has made these projects financially viable and thus, helps to offer lowest possible tariff to the rural households as well as small and medium business enterprises. Without any grant, the sponsors would have had to charge Tk.60 per kWh (US$ 0.7) to ensure minimum rate of return i.e. 15% on their equity investment. Even with 100% grant, the sponsor would have had to charge more than Tk.10 per kWh (US$ 0.11) to cover the operational expenses while ensuring their minimum return. The financing structure under IDCOL mini-grid projects is laid down in a way to encourage investors as well as to provide low-income groups with greater and more sustainable access to electricity.

1.2 Welfare Impacts of Electricity: A Brief Literature Review

Electricity is considered as a significant development indicator and its direct and indirect benefits has widely been recognized in cross country literatures (e.g. Khandker, Barnes and Samad, 2013; World Bank 2002, 2004, 2008; Roddis 2000; Barnes, Peskin, and Fitzgerald 2003; Kulkarni and Barnes 2004; Cabraal, Barnes, and Agarwal 2005; Khandker 1996; Filmer and Pritchett 1998). Evidences are also found that countries shift toward coal and natural gas, and finally nuclear power and modern renewables such as wind power, for their electricity needs as they develop (Burke, 2010). Therefore, welfare impacts of electrification have been analyzed in various literatures particularly for programs that tend to provide electricity in rural off-grid areas in developing countries. Evidences from both cross-sectional and panel surveys are found to depict patterns of development of rural electrification in several cross-country studies.

Using a cross-sectional survey conducted in 2005 among 20,900 rural households in Bangladesh; Khandker, Barnes and Samad (2012) examine the welfare impacts of household

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[1] 1 US$ = Tk. 84.9 (accessed from Bangladesh Bank as of Jan. 23, 2020).

access to grid electricity after controlling for endogeneity bias. The econometric analysis shows that grid electrification has significant positive impacts on household income, expenditure, and education. The household gain in total income due to electrification is as high as 21 percent, with a 1.5 percentage point reduction in poverty per year. Their results also suggest that income and expenditure effects of electricity connection are higher for better-off households.

In a study on South Africa, Dinkelman (2011) find that electrification significantly raises female employment within five years. This new infrastructure appears to increase hours of work for men and women, while reducing female wages and increasing male earnings. Several pieces of evidence further suggest that household electrification raises employment by releasing women from home production and enabling micro enterprises. In the Nepalese context, Abhiyan (2011) reported that Mini grid electrification has a positive impact on women's involvement in household decision making process. The author found that there is a 2 percentage point increase in the involvement of women on decisions related to children's education, general health and female health. Likewise, involvement of women on decisions related to household finance is 4 percentage points higher while participation of women in social gatherings has been higher by 3 percentage points.

Using a panel survey in rural Vietnam; Khandker, Barnes and Samad (2013) suggest that grid electrification has significant positive impacts on households' cash income, expenditure and educational outcomes. These benefits, however, reach a saturation point after prolonged exposure to electricity. A recent study on the benefits of solar homes systems in Bangladesh finds that the program saves Tk. 8775 million per year (Hossain et al., 2018). The reduction in kerosene consumption contributes to a reduction in indoor air pollution and creates external positive benefit on the health of household members. Children's study time and their completed years of education increases with SHS adoption, mainly for boys (Hossain et al., 2018). On the role of reliability benefits, Samad and Zhang (2016) find that electricity access combined with a reliable power supply is associated with a 17 percent increase in income during the sample period with a 9.6 percent increase in income is associated with access to electricity only in the Indian case. This policy appears to be progressive as lower-income households benefit more from access to electricity than higher-income households during the sample period. These welfare findings are found to be quite consistent with the longer-term impacts in rural India as highlighted by Vaan de Walle, Ravallion, Mendiratta and Koolwal (2013). They find that household electrification brought significant gains to consumption and earnings, the latter through changes in labor market supply. Interestingly, it also finds positive effects on schooling for girls but not for boys. However, one particular study on Rwanda reveals that effects on income and children's home studying become insignificant if regional differences are accounted for (e.g. Bensch, Kluve, and Peters, 2011).

Considering the huge potential of expanding renewable energy projects in Bangladesh, Hossain (2019) argues that the capacity building of banks and financial institutions, the development of bond and equity markets, a well-coordinated policy oversight body, and mainstreaming green finance are some of the key policy issues that Bangladesh needs to address to promote green financing and achieve sustainable development.

1.3 Objectives and scope of the Study

The objective of this study is to estimate the socio-economic benefits of mini-grid project of IDCOL. The scope of the impact assessment study on solar mini-grid project includes information collection on basic household characteristics, various modes of energy consumption, use of electronic and digital appliances, welfare impact of using such digital appliances, savings from kerosene consumption and resultant positive impact on environment, impact on health due to better lighting, increase of income through electricity-favorable IGAs etc. through structured questionnaires. Moreover, Information regarding efficient use of additional time in achieving adult/children educational outcomes, indoor air quality and other social activities has been accumulated using separate modules. A community survey has also been carried out in respective areas where household and business surveys were conducted. An additional questionnaire has also been administered on the mini-grid operators; covering their experience, education, investment, coverage, sales, profit etc.

1.4 Organization of the Report

The report has been organized as follows: Chapter 2 clarifies the survey design methodology while the socio-economic characteristics of the sample households are described in Chapter 3. Chapter 4 analyzes the current energy use pattern and time use of households. Impact Assessment of the solar mini-grid intervention with outcomes has been detailed in Chapter 5 and concluding remarks along with recommendations has been outlined in Chapter 6.

CHAPTER 2: METHODS AND APPROACHES

To assess the socio-economic benefits of solar mini-grid projects, this study mainly relies on quantitative analysis. For this purpose, a survey of beneficiary and non-beneficiary households was conducted through structured questionnaire. The sample size has been determined by applying the conventional sampling design formula as follows:

$$n = z^2{}_{\alpha/2} \frac{p(1-p)}{d^2} \times f$$

where, p is the proportion of the required characteristics in the population based on hypothesis rather than observed facts, $z_{\alpha/2}$ the value of the standardized percentile allowing α probability of bad samples, d the allowable margin of error and f is the design effect used for complex surveys using multi-stage cluster sampling. Conventionally, α can be taken as 0.05 and f can be taken as 1.5 to 2.0 for most socio-economic surveys in Bangladesh. For example, solar mini-grid electricity is new to many of the households, so theoretically, $p = 0.5$ gives the safest sample size since in this case $p(1-p)$ takes the highest value. A common choice for the value of the allowable margin of error is $d = 0.0025$. With $f = 2$ and considering anticipated non-responsive rate at 5% the above formula gives the required total sample size (household) to be is 768. However, after consultation with IDCOL, we finally decided to collect samples for the mini-grid interventions as follows: Treatment households: 1000; Control households: 1000.

2.1 Sample Distribution by Divisions

Table 2.1 represents the sample distribution across the locations. Among the treatment households, 493 appear to be purely mini grid users compared to 510 who are found to adopt both mini grid and solar home systems. Among the control households; 396 households do not have solar electricity and 604 households have only access to solar home systems (SHS).

Table 2.1: Sample distribution by divisions

Division	Adoption (%)		Non-adoption (%)	
	SMG	SMG+SHS	Only SHS	Control
Dhaka	13.79	38.43	20.20	18.43
Barisal	10.75	9.22	8.94	11.62
Chittagong	2.03	8.04	10.10	13.64
Khulna	1.42	6.47	3.64	3.28
Mymensingh	11.97	4.12	6.95	7.07
Rajshahi	27.99	23.92	30.79	26.26
Rangpur	32.05	9.80	19.37	19.70
Total	100	100	100	100
N	493	510	604	396

Source: BIDS Survey (2018).

The division-wise administrative survey data depicts that Rangpur division possess the highest percentages (approx. 32%) of mini grid users followed by Rajshahi (approx. 28%), Dhaka (approx. 14%), Barisal (approx. 11%) and Mymensingh (approx. 12%) divisions. Among the non-adopters; the north-western regions (i.e. Rajshahi and Rangpur divisions) demonstrates the majority of households who might have alternative energy sources as well as the highest percentage of households with access to SHS.

2.2. Community Survey

In addition to household survey, community survey was conducted in both treatment and control areas. Community survey included basic village characteristics, access to various infrastructures, IGA activities, price of alternate fuels and consumer goods, etc. The sample size for community surveys has been decided upon consultation with IDCOL. In particular, one community survey was conducted from each of the villages where household survey was conducted. A total of 80 villages was surveyed (Table 2.2).

Table 2.2: Sample Sizes for the Community (village) Survey

Component: Mini-Grid	Community/Villages surveyed		
	Treatment	Control	Total
No. of villages	50	30	80

2.3. Development of Instrument

2.3.1 Reconnaissance Survey

Before developing the questionnaire for the solar mini-grid survey, the IDCOL consultant and BIDS research team made a visit to Narsingdi area where a solar mini-grid has already been installed. The purpose of the survey was to examine the possible changes that are being made in the area as well as coverage of a mini-grid. The team also got a first-hand experience on pricing and other administrative aspects of Mini-grid and characteristics of the beneficiary households.

2.3.2 Instruments

Both structured and semi-structured questions were incorporated in the questionnaires designed for both household and enterprise survey. The questions incorporated in the questionnaires were based on the objectives of the study. In addition, while designing the questionnaire, similar types of studies conducted in Bangladesh and outside Bangladesh were reviewed and also consulted with the Consultant of the IDCOL. Three modules of questionnaires, such as household, community and sponsors (POs) were designed and administered. The questionnaires have broadly captured the following aspects.

Table 2.3: Key Issues in Specific Modules

Component	Specific Modules	Community Survey
Mini-Grid	- Household characteristics such as head's gender, age, education, household structure, sanitation etc. -Demographics of household member -Assets (Land, and non-land) -Education -Household income (**in details**) -Household expenditure (**in details**) -Time used for women and children -Attitude and opinion -Decision making in the household -Energy usage -Mini-grid facilities, tariffs and reliability of electricity	-Basic village characteristics -access to various infrastructures -IGA activities - price of alternate fuels and - consumer goods

2.4. Mobilization of Team

Formation of the survey team is the first step towards survey implementation. Team members have been hired based on their skills and experience in various aspects of the survey implementation process and a thorough knowledge of local and country-specific context. A database of professional enumerators and supervisors of about 100 with five years and more experience mostly in rural area surveys nationwide was reviewed for selection. From the database, 3 teams were formed consisting of 5 members including one supervisor in each of the team for the Mini-Grid surveys.

The supervisors and enumerators were recruited on the basis of their previous experiences on data collection and supervision. Minimum education qualification was graduate from social sciences or any other relevant subjects. For the supervisors, it was required to have at least five years of experience in field supervision activities. Supervisors were given the responsibility to supervise, coordinate, monitor and ensure validity of data collection.

Table 2.4: Survey Team Compositions

Teams	Teams	No. of team members in each team	Supervisor in each team
Mini-Grid survey	3	4	1

Also a data entry specialist and 10 data entry operators were recruited for entry, cleaning and processing of survey data. Finally, research team was appointed with the responsibility to ensure the overall success of the survey activities and data integrity. Table 2.5 highlights the responsibilities of various team members.

Table 2.5: Major Roles and Responsibilities of the Team Members

Team member(s)	Major roles
Research Team	• Ensures overall success of the data collection activities. • Participates in survey instrument development and recruitment of qualified enumerators • Leads interviewer training, and development of training materials. • Coordinate and synchronizes data collection and data entry efforts to finish them in a timely and efficient manner. • Is in charge of drafting the survey report.
Field Supervisors	• Explain the project to, and seek cooperation from, the community/local leaders of the selected villages. • Arrange interview appointments with households for the field enumerators with the help of village leaders. • Assign interviewing assignments to field enumerators, help them locate sample households, and manage field work . • Ensure collection and accuracy of data by monitoring field interviews, and reviewing completed questionnaires submitted by the field interviewers. • Conduct enterprise survey • Conduct community survey.
Field Enumerators	• Locate households and conduct surveys. • Ensure the accuracy and completeness of the collected data. • Consult with their supervisors to resolve any confusion and survey related issues as opposed to making decisions on their own. • Are prepared to revisit households if any missing or incomplete items are discovered in the questionnaires.
Data Entry Operators	• Enter data into the computer using standard statistical software • Validate entered data.
Data Cleaning and Estimation	• Clean the data to ensure internal consistency. • Derive estimates of descriptive statistics and conduct the tests of differences wherever applicable.

2.5. Training and Quality Control Measures

A two day-long extensive training program for the surveys were conducted for the preliminarily selected enumerators on the use of questionnaire. They were given adequate knowledge about SMG as well as selection of the respondents. Moreover, they were given instructions on how to collect different information from the households and enterprises. After the training, a **field-testing** of the questionnaire was done in two villages in Daulatpur upazila of Manikganj. All the selected enumerators and supervisors were participated in the field-testing process.

2.6. Pretesting the Survey Instruments

Before administering each of the four surveys, pre-testing of the questionnaires was conducted. The objective of pretesting is to test the questionnaires and the overall preparedness of the survey team in conducting the actual survey. More specifically, pre-testing helps to identify if there is any problem in the questionnaire in terms of its language, logic and sequence. It is important to test whether a question, in the way it is phrased, is able to elicit the right response from the respondent. Pre-test gives a good opportunity to verify that. Also, questions sequenced in right order (with proper skip pattern) and logic is likely to be answered more accurately than when they are not. Furthermore, pretesting ensures that the codes of close-ended questions are as exhaustive as possible; in particular, they take into account all the possibilities that are relevant to the country and local context. Moreover, pretesting provides the survey team personnel an opportunity to determine the expected duration for a household interview, and on that basis, the total time duration for conducting the whole survey can be estimated. Pretesting also provided the survey team an opportunity to evaluate the logistics and administration for the actual survey.

The pre-testing process was completed in two phases which are described below.

2.7. Preparation of the Survey Team

All the selected enumerators and supervisors had participated in the pre-testing process. Ideally, pre-testing is done in places away from the actual survey locations having similar conditions to actual survey areas. Considering the similarity of the households in actual survey areas, pre-testing was done in the Daulatpur upazila of Manikganj. The reason for selecting this district is that Solar home systems are available in many of the households in this area.

2.8. Administering Pretesting Interviews

Households selected for the pretesting were different from the ones selected for the actual surveys to ensure that pretesting does not influence or bias the households during the actual interviews. The survey team was provided vehicles for their transport to the specific villages, and they were equipped with necessary supplies as they would have been during the actual surveys, such as, the questionnaires, necessary authorization letters, and stationery. The BIDS representatives went to the villages to monitor pretesting interviews. Activities during the pretesting were including:

i. Carry out the interviews in entirety;

ii. Time calculation for each interview accurately, and make note of questions that take more than expected time;

iii. Check the questions for their logic, sequence and phrasing, and make note of questions that seem to confuse the respondents, make them hesitate or sensitive. Especially, all types of non-response should be carefully noted and distinguished, such as, “Do not know”, “Refuse to answer”, etc.; and

iv. Make note of categorical questions where the responses are outside the range of listed responses.

The details of the pre-testing are given in Table 2.6.

Table 2.6: Information on Pre-Testing Survey Instruments

RETs	Pre-testing dates	No. of treatment HHs interviewed	No. of control HHs interviewed	No. of communities surveyed	No. of POs surveyed	Name of villages/districts
Solar Mini-Grid	04/09/2018	10	10	2 (1 treatment; 1 control)	1	Villages: Mondalpara, Vangapara Union-Char Bagutia, Upazila-Daulatpur, District-Manikganj.

CHAPTER 3: BACKGROUND CHARACTERISTICS OF SAMPLE HOUSEHOLDS

This chapter reports the socio-demographic characteristics, level of education, employment and occupation pattern, access to housing, water and sanitation, asset holdings, income, expenditure and energy consumption patterns. This analysis is important for drawing valid inferences on the impact of intervention by controlling these factors. However, we do not tend to infer any causality at this stage. Some of the characteristics may have been instrumental in adoption of solar mini grid while some others may partly be explained due to solar mini grid adoption.

3.1 Socio-Demographic Characteristics and Education level of the Households

Table 3.1 displays the demographic characteristics of the sample households and depicts the comparative scenario among different groups of adopters and non-adopters. The general pattern of household size shows that there is no significant difference exists among the treatment and control groups with the average being somewhat between 5 and 6. A significant difference is found in the overall average age pattern (27.67 years vs. 26.26 years). Similar parallel pattern is also seen among different groups of treatment and control with regards to proportion of female-headed households in the existing sample(s). About 7% female-headed households are pure SMG users while around 9% seems to adopt both SMG and SHS.

Table 3.1: Demographic characteristics of the households

Indicator	Treatment			Control			Diff.	p-value
	SMG	SMG+SHS	Overall (Avg.)	Only SHS	Control	Overall (Avg.)		
Sex ratio	1.37	1.34	1.36	1.40	1.27	1.35	0.01	0.85
Age (Years) (Avg.)	26.60	28.70	27.67	26.79	25.45	26.26	1.41	0.00
Married (%)	50	52	50.80	49	48	48.60	2	0.32
Unmarried (%)	46	44	45.31	47	46	46.77	-1	0.51
Widowed/divorced/ separated	4	4	3.9	4	4	4.6	-	-
Proportion of female headed HH (%)	7	9	7.98	6	9	6.90	1	0.36
Household Size	5.18	5.86	5.53	5.33	4.50	5	0.53	0.00

Source: BIDS Survey (2018).

Since the choice of SMG adoption is restricted only in the areas where SMG is being implemented, education level and other characteristics maybe considered as given. Most of the respondents in both treatment and control area appear to have primary education (about 30%) or no formal education (about 25%) (Table 3.2). That implies that 75.44% of sole mini grid users have ever attended school compared to 68.32% of the respondents who are pure control households (i.e. households who might have alternative energy sources).

Table 3.2: Level of education for individuals between aged five and above (%)

Schooling completed	Treatment			Control			Diff.	p-value
	SMG	SMG+ SHS	Overall (Avg.)	Only SHS	Control	Overall (Avg.)		
Never went to school	24.56	15.49	19.95	26.50	31.68	28.55	-8.60	0.00
Class I to Class V	32.76	28.27	30.47	35.07	36.40	35.60	-5.12	0.01
Class VI to Class IX	17.78	23.43	20.65	16.92	11.03	14.59	6.07	0.00
SSC Level	3.70	7.82	5.80	2.92	1.46	2.34	3.45	0.00
HSC Level	2.66	4.85	3.77	1.57	0.41	1.11	2.66	0.00
Undergraduate to Post Graduate	2.44	5.59	4.04	1.16	0.38	0.85	3.19	0.00
Trade course/Religious schools/madrasa	1.4	1.38	1.39	1.78	1.57	1.69	-0.3	0.56
Total N	493	510	1003	604	396	1000		

Source: BIDS Survey (2018).

3.2 Employment and Occupation

Employment pattern does not vary across SMG adopters and non-adopters. Table 3.3 suggests that over 80% household heads are employed in both groups with a slightly higher proportion in the control households (83.1% vs 89.3%). The prominent employment categories include wage laborers in agriculture (8.97% vs 19.70%), wage laborer in non-agriculture (9.27% vs. 17.90%), self-employed in agriculture (26.82% vs. 27.30%), business (16.85% vs. 9.10%) etc. (Table 3.3). Among the treatment group, the dominant occupations are business and self-employed in agriculture. This is expected because mini-grid projects usually target business friendly locations from its viability concerns.

Table 3.3: Employment by Occupation (%) (for HH head)

Employment Category	Treatment			Control			Diff.	p-value
	SMG	SMG + SHS	Overall (Avg.)	Only SHS	Control	Overall (Avg.)		
Wage laborers in agriculture	14.60	3.53	8.97	13.91	28.54	19.70	-10.73	0.00
Wage laborers in non-agriculture	13.79	4.90	9.27	14.74	22.73	17.90	-8.63	0.00
Salaried employee	5.07	13.33	9.27	3.31	3.54	3.40	5.87	0.00
Self-employed in agriculture	27.59	26.08	26.82	33.11	18.43	27.30	-0.48	0.81
Self-employed in non-agriculture	1.42	0.39	0.90	0.99	0.25	0.70	0.20	0.62
Business	12.98	20.59	16.85	11.42	5.56	9.10	7.75	0.00
Transport owner/Business	3.45	4.12	3.79	2.48	3.03	2.70	1.09	0.17
Fisherman/Carpenter/Meissonier/Weaver/Various repair work/Contractor Hawker/Barber/Tailor	6.09	3.73	4.89	7.63	6.31	7.1	-2.21	0.57
Self-employed professionals/Other self-employment	2.23	2.55	2.4	1.49	1.27	1.4	1	0.4

Total N	493	510	1003	604	396	1000		

Source: BIDS Survey (2018).

Note: Statistical significance indicates p value <= 0.05 i.e. here, in cases p value >0.05 denotes the difference between the treatment and the control group is not statistically significant exhibiting their similarity.

3.3 Housing, Water and Sanitation

Housing pattern is found to be better in the treatment households compared to that of the control households. In Table A2 (see Appendix-I), it can be seen that majority of the respondents dwell in their own house. The percentage of owned homes is significantly higher for the overall treatment groups at 77.07% than the overall control groups at 66.90%. About 10.27% of the overall treatment and 11.80% of the overall control groups rent or lease their homes to others. The percentage of persons paying no rent at 21.30% is significantly higher in the overall control groups than that of 12.66% in the overall treatment group. The average number of rooms excluding the bathrooms, storage and cow sheds remains significantly different for overall treatment (2.80) and control (2.13) groups respectively.

Regarding the access to hygienic sanitation, the overall treatment group consists of 90.23% which is significantly higher than the overall control group of 86.40%. Access to arsenic free tube well water was also found to be at 54.94% in the overall treatment households compared to 50.90% in the overall control households. The distance of latrine from the treatment and control households significantly varies between 22-25 ft. on average.

Table A3 (see Appendix-I) presents data on the construction materials used for floor, walls and roof. It shows that mud is the most commonly used material for flooring for both the overall treatment and control groups at 76.37% and 95.40% respectively. For walls and roof, the most widely used material is CI sheet (Tin). Overall, on average around 81.16% of treatment households use CI sheet (Tin) on walls compared to 76.70% of the control households and is statistically different. Similarly, around 97.51% represents the average treatment household respondents of CI sheet (Tin) users on roof with around 96.30% being in the overall control group. However, household responses between overall treatment and control seem to vary significantly in the usage of other materials in floors, walls and roofs.

3.4 Household Assets, Income and expenditure

Treatment households appear to be well off compared to the control households (Table 3.4).

Table 3.4: Types and Value of Assets (in Tk)

Types of Asset (Tk)	Treatment			Control			Diff.	p-value
	SMG	SMG+ SHS	Overall (Avg.)	Only SHS	Control	Overall (Avg.)		
Land and Homestead	953094.4	1878378	1423578	679737.4	193783.8	487299.7	936277.8	0.00
Tools and appliances (Agri. And Non-agri.)	9286.379	12163.98	10749.57	18418.69	4722.298	12994.9	-2245.35	0.38
Industrial and business assets	14930.02	150492.2	83859.9	11548.2	1530.366	7581.135	76278.8	0.00
Transportation assets (both energy consuming and not)	25138.54	64030	44913.86	21871.11	3213.005	14482.5	30431.36	0.03
Livestock, aquaculture and tree	61438.33	96640.97	79337.98	71355.44	35378.73	57108.67	22229.31	0.00
Household furniture and equipment	22684.63	64863.65	44131.59	29226.24	8519.561	21026.4	23105.2	0.00
Financial assets	54050.14	158659.9	107241.5	60216.33	21148.83	44745.6	62495.94	0.00
Debts	38561.17	75500.36	57343.81	48576.01	24764.41	39146.61	18197.19	0.00
Total assets	1140622	2425229	1793812	892373.4	268296.6	645239	1148573	0.00
Total	493	510	1003	604	396	1000		

Source: BIDS Survey (2018).

Among physical assets, land and homestead appears to be the main valuable asset of the households (Tk. 1423578 vs. Tk. 487299.7); followed by Industrial and business assets (Tk. 83859.9 vs. Tk. 7581.135), livestock, aquaculture and trees (Tk. 79337.98 vs. Tk. 57108.67), transportation assets (both energy consuming and not) (Tk. 44913.86 vs. Tk. 14482.5) and furniture and equipment (Tk. 44131.59 vs. Tk. 21026.4). On average, it can be seen that land and homestead, industrial and business, transportation assets, livestock, aquaculture and trees and household furniture and equipment held by the members of the treatment groups are significantly higher compared to that of the control groups. However, the overall control group is found to possess higher amount of tools and appliances (agri. and non-agri.) compared to the overall treatment group (Tk. 12994.9 vs. Tk. 10749.57), although not significant. Besides land and homestead, households also reported the value of non-physical assets in monetary terms. Among non-physical assets i.e. financial assets; overall, the treatment households are found to hold significantly higher amount (Tk. 107241.5) of liquid assets compared to that of the control households (Tk. 44745.6), on average. Overall treatment group is found to be significantly better-off with regards to asset-holding compared to the overall control group (Tk. 1793812 vs. Tk. 645239).

Income and expenditure of the treatment households are significantly higher than the control households (Table 3.5). The findings suggest that total income and expenditure are found to be significantly higher for the treatment groups compared to the control groups. Total income coming from both agricultural and non-agricultural sources is significantly higher for the treatment households compared to the control ones (Tk. 270384 vs. Tk. 168546.20). Among them, although differences in annual income from non-agricultural activities (Tk. 196525.1 vs.

Tk. 98402.85) is found to be statistically significant, differences in annual income from agricultural activities is not statistically significant (Tk. 73858.94 vs. Tk. 70143.3), with the treatment households accruing a higher amount than the control households.

Similarly, the total expenditure of the control households is also found to be significantly lower than the treatment households (Tk. 141046.80 vs. Tk. 204755.50). Among the expenditure categories; on average, total food expenditure (Tk. 94375.02 vs. Tk. 74301.50) and total non-food expenditure (Tk. 110380.40 vs. Tk. 66745.29) are also found to exhibit consistent patterns for both the overall treatment and control groups respectively. However, these patterns are not surprising as the overall treatment households are found to be significantly better-off compared to the overall control households as depicted through per capita net income (Tk. 12572.75 vs. Tk. 6039.91), on average.

Table 3.5: Household income and expenditure (yearly)

Sources of Income and expenditure (taka) yearly	Treatment			Control			Diff.	p-value
	SMG	SMG+ SHS	Overall (Avg.)	Only SHS	Control	Overall (Avg.)		
Total annual income (both Agri. and Non-agri. sources)	186261.6	351702.3	270384	188662.2	137864.1	168546.2	101837.9	0.00
Annual income from agricultural activities (avg.)	57092.15	90066.85	73858.94	79482.87	55898.09	70143.3	3715.645	0.51
Annual income from non-agricultural activities (avg.)	129169.5	261635.5	196525.1	109179.3	81966	98402.85	98122.21	0.00
Annual expenditure (avg.)	144876.90	262638.10	204755.50	160706.20	111061.20	141046.80	63708.68	0.00
Total food expenditure	78950.56	109285.30	94375.02	82831.09	61291.72	74301.50	20073.52	0.00
Total non-food expenditure	65926.34	153352.70	110380.40	77875.14	49769.45	66745.29	43635.15	0.00
Annual per capita income	38772.41	64010.99	51605.58	36608.69	31629.36	34636.88	16968.71	0.00
Annual per capita expenditure	10614.56	23345.33	17087.83	12364.1	8716.306	10919.57	6168.261	0.00
Per capita net income	9227.09	15806.89	12572.75	5813.42	6385.35	6039.91	6532.84	0.00

Source: BIDS Survey (2018).

3.5 Poverty Status of the Households

We also examine the poverty status of the households using *Foster, Greer, and Thorbecke* (1984) technique, dubbed as the FGT method. Poverty (as well as extreme poverty) is measured with the help of three indices–namely, (a) the headcount poverty index (P_0), which measures the proportion of the population counted as poor, i.e., whose consumption expenditure falls below the poverty line (b) the poverty gap index (P_1), which measures the average depth of poverty, i.e. on average, how far below the poverty line the poor people's consumption happens to lie and (c) the squared poverty gap index (P_2), which also measures the average depth of the poverty but it is a weighted average; with greater weights being assigned to the gaps of the poorer persons. As the headcount poverty rate gives only the percentage value of poverty incidence and does not measure the distance of the poor households from the poverty line, the poverty gap estimates about the depth and severity of poverty of the population are required.

Table 3.6 presents estimates of all three measures of poverty among the treatment and control groups across the types of intervention envisaged. The estimates reveal the process of accelerated poverty reduction in the rural areas. The headcount rate, using the upper poverty line[2] has been estimated at 45.86% for treatment groups and 63.20% for control groups. However, using the lower poverty line, it can be seen that the proportion of poor is estimated at 26.42% for treatment groups and 44.80% for control groups.

Table 3.6: FGT Measures of Poverty Based on Expenditure

FGT Indices	Treatment	Control	Diff.
Upper (Moderate) Poverty Line			
Headcount	45.86	63.20	-17.34
Poverty Gap	1.70	4.50	-2.81
Squared Poverty Gap	3.44	6.15	-2.71
Lower (Extreme) Poverty Line			
Headcount	26.42	44.80	-18.38
Poverty Gap	0.50	1.00	-0.50
Squared Poverty Gap	1.34	2.71	-1.37

Source: Authors' calculations.

Using the upper poverty line, the poverty gap has been estimated at 1.70% for treatment households and 4.50% for control households. Similarly, using the lower poverty line, the poverty gap has been estimated at 0.50% for treatment groups and 1.00% for control groups. The squared poverty gap measures the severity of poverty. Using the upper poverty line, the squared poverty gap has been estimated at 3.44% in the case of treatment households and 6.15% in the case of control households. Using the lower poverty line, the squared poverty gap has been estimated at 1.34% for treatment groups and 2.71% for control groups. Thus, even though rates of moderate and extreme poverty have declined in rural areas between 2010 and 2016, the depth and severity still remain a cause of concern in some pockets.

[2] The upper and lower poverty lines through updates of BBS 2016 estimates were used in head counts i.e. The poverty line is set at 1862 units (lower) & 2268 units (upper).

CHAPTER 4: CURRENT STATUS OF ENERGY CONSUMPTION AND TIME USE

This chapter gathers information on alternative energy use besides solar mini grid, detailed use of electric and non-electric appliances/gadgets by households, sources of knowledge behind adoption of mini grid, features of fuel requirement and alternative sources, average time use for women and children and women's income generating activities etc. The purpose is to understand the energy consumption pattern of the households.

4.1 Current Status of Alternative Energy use among Households

Around 55.23% of treatment households use an alternative electricity source besides solar mini grid. However, about 88.48% use SHS and the rest use other sources including kerosene lamps (5.85%), rechargeable lanterns (2.66%), candles (2.13%) and others (0.88%). SHS is used for about 7.24 hours and usage of other sources includes 5.25 hours for generator in treatment households. Similarly, the majority of control households use solar home systems (60.40%) for electricity. Around 38.80% of the control households do not have access to any forms of electricity (Table 4.1).

Table 4.1: (Alternative/Main) Sources of electricity for Treatment/Control HHs

Indicator	**Treatment (% Duration)**	**Control (% Duration)**
Percentage of HHs that use an alternative electricity source other than SMG	55.23	--
HHs with access to electricity (%)	--	61.20
Sources of Electricity (Alternative of SMG/Main)		
Solar home system (SHS)	88.48	60.40
Generator	0.35	0.10
Kerosene lamps	5.85	--
Candles	2.13	--
Rechargeable battery	--	0.10
Solar lanterns	0.18	--
Flashlights (torch)	0.35	--
Other	2.66	0.60
No electricity	--	38.80
Time use using this source for electricity (hours/day)		
Solar home system	7.24	22
Generator	5.25	4
Kerosene lamps	1.49	--
Candles	2.57	--
Solar lanterns	.5	--
Rechargeable battery	--	10
Flashlights (torch)	1	--
Other	1.03	8.17

Source: BIDS Survey (2018).
Note: The empty cells represent the non-users/responses in the corresponding category.

Table 4.2: Current status of electricity in households (Control HHs)

Source	Average length of time it has been used (months)	Average duration of electricity received per day sources (hours/day)	Average amount of electricity received in the evening(between 6-10 pm) (hours)	Monthly electricity bills paid on the usage(Tk.) (Avg.)
SHS	63.73	22	3.95	22.59
Generator	5	4	4	
Rechargeable battery	24	10	4	
Other	24	8.17	4	

Source: BIDS Survey (2018).

A large number of control households have been using SHS for around 64 months and the average duration of SHS usage is 22 hours per day. The other sources of electricity are rechargeable battery (24 months with 10 hours/day), generator (5 months with 4 hours/day) and others (24 months with 8.17 hours/day). As expected, the average use of electricity in the evening (between 6-10 pm) has been found homogenous for all sources i.e. SHS, generator, rechargeable battery and others which are around 4 hours. The average monthly cost for SHS use is found to be around Tk. 22.60 (Table 4.2).

4.2 Electric and Non-Electric Appliances/Gadgets in the Households

The treatment households use on average more than 3 LED bulbs/lights of different attributes and 2 fans (Table A1 in appendix). It was found that households use cooling fans of various types, charger lanterns, and mobile chargers. Besides, a meager number of households use SHS electricity for watching BW and LED color televisions as well as cassette players. The control households that have SHSs, use on average 1 LED/Tube light and 1 fan.

We asked the households about the capacity of electric appliances. According to their opinion, they use energy saving bulbs of about 25-32 WP; tube lights and the LED bulbs having capacity of 7-21 WP. The power consumption of entertainment appliances is higher than the light bulbs, fans and other devices. Whatever the types of lights, fans, entertainment, and ancillary devices used in the households, these are used for 2-4 hours daily as the captive electricity from the SHS cannot support longer period of usage.

4.3 Sources of Information and Issues related to Solar Mini-Grid

The sources of information regarding SMG adoption could be important instruments for further econometric analysis as well as program expansion. Therefore these are highlighted in Tables 4.3 and 4.4 for both treatment and control households respectively.

About 96.11% of the treatment households mentioned the SMG Company as their primary source of information. This is followed by friends or neighbors (90.43%), village leader (57.53%), from announcements in the village (52.54%), village meetings (39.58%) and brochures/leaflets/posters (4.29%) respectively. The average distance of a treatment household from mini grid station and electric pole is 1280.70 meter and 55.98 ft. respectively. On the other hand, Control households were chosen from the neighborhood of SMG area, and therefore a large number of control households know about SMG (98.90%), among which around 97.88% of the control households availed this information from friends or neighbors. The other sources of information include village leader (61.48%), SMG Company (36.40%), village meetings (27.81%), announcements in the village (24.57%) and from brochures/leaflets/posters (1.42%) respectively. The average distance of a control household from mini grid station and electric pole is 2711.70 meter and 977.75 meter respectively (Table 4.3).

Table 4.3: Sources of Knowledge and Accessibility of Solar mini-grid

Category	**Treatment HHs**	**Control HHs**
Percentage of HHs that know about SMG	--	98.90
Sources of knowledge about solar mini-grid (%)		
From SMG company	96.11	36.40
From village leader	57.53	61.48
From village meetings	39.58	27.81
Brochures/leaflets/posters	4.29	1.42
Friends/Neighbors'	90.43	97.88
From announcements in the village	52.54	24.57
Accessibility of solar mini-grid		
Average distance of house from mini grid station (meter)	1280.70	2711.70
Average distance of house from mini grid pole (ft.)	55.98	
Average distance of house from electric pole (meter)		977.75
Average amount of costs incurred for availing mini grid connection (tk.)	4062.84	
Average amount of costs incurred for internal wiring (tk.)	2820.76	
Charge per unit of electricity consumed from SMG (Tk./kWh) (Avg.)	26.56	
Amount of electricity consumed from SMG (kwh/month) (Avg.)	494.82	
Percentage of HHs that will connect to SMG if available		74.60

Source: BIDS Survey (2018).

The average amount of costs incurred for availing mini grid connection is Tk. 4062.84 and the average charge per unit of electricity consumed from SMG is Tk. 26.56 per kWh. Around 96.61% of the treatment households use pre-paid payment system while the average estimated amount sustained in appliance damage is Tk. 798.21 (Table 4.4).

Table 4.4: Payment system and constraints of SMG connections

Payment system of SMG connection (%)	**Treatment HHs**
Pre-paid	96.61
Post-paid	3.39
Percentage of HHs that incurred appliance damage due to voltage fluctuations	8.37
Estimated amount sustained in appliance damage (tk.) (avg.)	798.21
Reasons for not connecting to SMG (%)	**Control HHs**
Cannot afford connection cost	31.50
Cost of SMG electricity is very high	50.79
Content with current situation	12.60
Transformer location is too far/SMG reliability is not satisfactory/Other	5.11

Source: BIDS Survey (2018).

The control households identified various reasons for not connecting to solar mini grid. Among them; the majority (50.79%) mentioned that cost of SMG electricity is very high which has been followed by connection cost unaffordability (31.50%) and others (5.11%) respectively. Nonetheless, about 12.60% of the control households are also found to be content with the current situation as well (Table 4.4).

4.4 Features of Fuel Acquirement and Alternative Sources

Besides electricity, both treatment and control households are also found to use other forms of energy sources e.g. kerosene, candle, dry cell etc. (see Table 4.5). The average monthly consumption of kerosene by the treatment households is around 0.080 liters while it is significantly higher in control households (i.e. around 0.89 liters for all including SHS users and 2.09 liters for HHs without SHS). Thus adoption of SMG electricity saves monthly consumption of 2 liters kerosene, that is about Tk. 136 (Tk. 68/liter). This is followed by number of candles (0.15 vs. 0.39) and number of dry cells (0.003 vs. 0.031) for both overall treatment and control households respectively. In both the latter cases, the differences are found to be statistically significant.

Table 4.5: Alternate fuels and energy sources used for lighting and electricity needs (month)

Fuel source	Treatment			Control			Diff.	p-value
	SMG	SMG+ SHS	Overall (Avg.)	Only SHS	Control	Overall (Avg.)		
Kerosene (liter)	.1290061	.0328431	.0801097	.1050497	2.079293	.88685	-.8067403	0.0000
Candle (number)	.3083164	.0039216	.1535394	.3692053	.4217172	.39	-.2364606	0.0122
Dry cell (number)	.0040568	.0039216	.003988	.0298013	.0328283	.031	-.027012	0.0224
Costs incurred for acquiring fuels (Tk./month)	11.42394	2.429412	6.850449	9.937086	152.7803	66.503	-59.65255	0.0000
Usage of fuels in different activities								
Percentage share of fuels used for cooking/parboiling	4.23	30.91	9.16	10.53	1.30	3.04	6.12	0.00
Percentage share of fuels used for lighting	92.11	50.91	84.50	71.26	96.30	91.59	-7.09	0.01
Percentage share spent on other work	3.66	18.18	6.34	18.21	2.40	5.37	0.97	0.66

Source: BIDS Survey (2018).

The survey results further informed us regarding the usage of fuels in different activities e.g. cooking/parboiling, lighting and other works. The primary use of fuels is found for lighting (84.50% vs. 91.59%) which is followed by cooking/parboiling (9.16% vs. 3.04%) and other works (6.34% vs. 5.37%) respectively.

4.5 Average Time Use for Women and Children

Table 4.6 displays the average time use for women in various household chores, activities during spare time and own income generating activities and business as reported by women household members from both treatment and control households. The average time use has been recorded in minutes by the enumerators.

Table 4.6: Average time use for women in 24-hours (min) (Except sleep at night)

Types of activities	Treatment			Control			Diff.	p-value
	SMG	SMG+ SHS	Overall (Avg.)	Only SHS	Control	Overall (Avg.)		
Wage/salaried work	3.65	10.29	7.03	0.79	3.56	1.89	5.14	0.01
Own income-generating activities/business	16.65	20.50	18.61	20.79	20.83	20.81	-2.20	0.26
Household work/chores	83.98	81.51	82.72	83.72	80.28	82.35	0.37	0.85
Cooking/preparing meals/boiling water/cleaning stoves	139.69	134.15	136.88	131.99	134.37	132.93	3.95	0.09
Eating/serving meals (including carrying food to husband's workplace/field)	51.92	42.89	47.33	47.39	46.02	46.85	0.48	0.71
Washing clothes and other cleaning activities	62.23	57.80	59.97	60.01	58.60	59.45	0.52	0.69
Collecting fuel	41.09	28.89	34.89	34.70	38.48	36.20	-1.31	0.41
Collecting water	21.41	17.89	19.62	21.66	22.22	21.88	-2.26	0.00
Reading and studying	0.47	0.64	0.55	0.22	0.35	0.27	0.28	0.19
Using mobile phones for conversation only/Using mobile phones for accessing information and knowledge	8.57	13.91	11.29	9.64	5.85	8.14	3.15	0.01
Taking care of children (incl. bathing, feeding, dressing etc.)	56.67	54.40	55.52	57.70	66.45	61.16	-5.65	0.10
Helping with children's study/homework	21.84	21.99	21.92	18.64	15.62	17.45	4.47	0.00
Watching television	4.02	12.98	8.57	0.66	0.15	0.46	8.11	0.00
Socializing, visiting neighbors, friends, relatives, entertaining guests	55.96	62.53	59.30	59.92	64.26	61.64	-2.34	0.25
Listening to radio/Attending Community activities, meetings	1.05	1.26	1.16	1.59	1.46	1.54	-0.5	0.24
Resting, taking daytime nap, etc.	101.87	106.69	104.32	102.94	100.37	101.92	2.40	0.32
Religious activities	58.61	61.28	59.97	60.76	57.01	59.27	0.70	0.62
Total	729.68	729.62	729.65	713.11	715.89	714.21	15.43	0.03

Source: BIDS Survey (2018).

The findings suggest that on average, the overall treatment households spend around 136.88 minutes per day in cooking/preparing meals/boiling water/cleaning stoves compared to 132.93 minutes per day usage by the overall control households. This information has been followed by household work/chores (82.72 min. vs. 82.35 min.), religious activities (59.97 min. vs. 59.27 min.), socializing, visiting neighbors, friends, relatives, entertaining guests (59.30 min. vs. 61.64 min.), taking care of children including bathing, feeding, dressing etc. (55.52 min. vs. 61.16 min.), washing clothes and other cleaning activities (59.97 min. vs. 59.45 min.), eating/serving meals including carrying food to husband's workplace/field (47.33 min. vs. 46.85 min.), helping in children's study/homework (21.92 min. vs. 17.45 min.), women's own income-generating activities/business (18.61 min. vs. 20.81 min.) and watching television (8.57 min. vs. 0.46 min.) for SMG (treatment) and non-SMG (control) households consecutively. Interesting insights could be drawn from average time use pattern in activities such as resting, taking daytime nap, etc. and collecting water. On average, the overall treatment households spend around 104.32 minutes which is higher than the overall control households average time use of around 101.92 minutes for the same, although not significant. However, the SMG households requires significantly lesser time for collecting water (i.e. 19.62 minutes) compared to the non-SMG households (i.e. 21.88 minutes). On the whole, the total accumulated average time use for the overall treatment groups (i.e. 729.65 min.) is found to be significantly higher compared to the overall control groups (i.e. 714.21 min.). This justifies the **time savings** due to adoption of solar mini grid which subsequently releases more time for other household activities and spare time use for women members of the treatment households.

4.6 Women's Income Generating Activities

It is assumed that women's affiliation in income-generating activities (IGAs) inside and outside home is an important indicator for women empowerment. The questionnaire survey recorded detailed information on women's engagement in various income-generating activities, time usage in IGAs and monthly net earnings out of IGA business inside and outside home and the results are shown in Table 4.7 below.

Table 4.7: Women's Income Generating Activities

Categories	SMG households			Non- SMG HHs			Diff.	p-value
	SMG	SMG+ SHS	Overall (Avg.)	Only SHS	Control	Overall (Avg.)		
Engaged in IGA	27.38	33.53	30.51	26.16	31.82	28.40	2.11	0.30
IGA at Home	100	100	100	100	98.55	99.37	0.63	0.14
IGA outside home	0.00	0.00	0.00	0.00	1.45	0.63	-0.63	0.14
Major Types of IGAs								
Weaving and Tailoring	1.35	1.05	1.18	0.56	0.72	0.63	0.55	0.46
Making clothes	10.14	9.42	9.73	9.50	6.52	8.20	1.53	0.49
Rearing Livestock	10.81	6.81	8.55	11.73	13.77	12.62	-4.06	0.09
Rearing poultry	76.35	80.10	78.47	73.18	73.91	73.50	4.96	0.14
Cane/Bamboo work/Pottery/Grocery/ stationary shop/Other	1.35	2.61	2.05	5.02	5.06	5.05	-2.99	0.34
Time you spent in IGAs (min/day)	58.45	59.87	59.25	67.63	65.00	66.48	-7.23	0.05
Monthly Net Earnings (Tk.)	410.64	447.98	431.68	515.92	391.78	461.87	-30.19	0.63

Source: BIDS Survey (2018).

It is found that around 30.51% of the overall treatment households are engaged in IGAs compared to 28.40% of the overall control households. Among them, about 100% of the SMG households conducted IGAs at home compared to about 99.37% of the control households. A meager amount of IGA (0% vs. 0.63%) are seen to be conducted outside home by both SMG and non-SMG households. Among the numerous types of IGAs; around 8.55% of the treatment group reared livestock than 12.62% of the control group which has been followed by rearing poultry (78.47% vs. 73.50%). Among other IGAs, making clothes (9.73% vs. 8.20%), grocery and stationary shop (0.59% vs. 0.32%), weaving and tailoring (1.18% vs. 0.63%) and other activities (0.88% vs. 1.58%) had been mentioned by SMG and non-SMG respondents consecutively. However, around 3.15% of the non-SMG respondents are found to do cane or bamboo work that are significantly higher than 0.29% of the SMG respondents. On average, the treatment households spent around 59.25 min. in IGAs compared to around 66.48 min. time usage of the control households with the difference being statistically significant. Intriguingly, the monthly net earnings of the treatment households were estimated at Tk. 431.68 which is lower than the estimated monthly net earnings of the control households i.e. Tk. 461.87 for the reported IGAs, albeit not significant.

4.7 Attitude and perceptions towards solar mini grid

This section highlights the opinions of the respondents to understand their attitude and perceptions towards solar mini grid. The findings regarding the opinions, as depicted in Table A4 (see Appendix-I), suggest that most of the respondents strongly agree to the statements like having electricity is important for children’s education, children have extended their studying time at nights because of good light, we can study during the evening because of good light, reading is easy/comfortable with electric light compared to that with candles, kerosene lamps/lanterns, electricity has made the inside of our household smoke-free, SMG is reliable and beneficial, expense related to mini grid electricity purchase is very high and a financial burden to our family and electricity from mini grid ensures night security. Most of the responses in these statements varies between strongly agree and agree with extremely minimal non-adhere (disagree and strongly disagree) responses.

Besides, in two particular statements such as because of electricity we are connected to the world information, news, etc. and electricity is benefiting our community through improved economic and enterprise development; most of the respondents ‘agreed most’ compared to ‘strongly agree’ as of the other statements. However, in all of these statements the differences between the overall treatment and control groups are significant indicating the adopters’ better perceptions towards agreeable responses.

CHAPTER 5: IMPACT OF SOLAR MINI GRID ADOPTION: OUTCOMES AND REGRESSION RESULTS

This chapter analyses the impact of SMG electricity on household welfare, particularly on education, income and expenditures. In addition to descriptive statistics, we have used OLS regressions as well as Instrumental variables (IV) Regressions.

5.1 Descriptive Statistics

5.1.1 Impact on Educational Outcomes

Educational outcomes have been measured in terms of evening study time duration, school attendance and completed years of grades for both boys and girls aged 5-18 and the results have been displayed in Table 5.1.

Table 5.1: Education outcomes (for children aged 5-18)

Outcome Variable	SMG HHs			Non- SMG HHs			Diff.	p-value
	SMG	SMG+ SHS	Overall (Avg.)	Only SHS	Control	Overall (Avg.)		
Evening study duration (minutes/day)								
Boys	94.22	115.69	105.64	96.43	87.91	93.19	12.45	0.00
Girls	98.36	111.02	104.95	97.29	89.30	94.29	10.67	0.00
School attendance (%)								
Boys	74.46	85.00	79.72	69.38	70.36	69.75	9.97	0.00
Girls	81.98	85.46	83.76	81.21	81.97	81.50	2.26	0.23
rades completed (years)								
Boys	7.62	6.87	7.22	8.28	7.11	7.84	-0.62	0.48
Girls	4.87	6.62	5.78	5.22	5.07	5.16	0.61	0.33

Source: BIDS Survey (2018).

The findings show that study duration (minutes/day) has significantly increased for both boys and girls in the overall SMG adopted households compared to the non-SMG adopted ones. Similarly, school attendance is found to be significantly lower in the overall control households than the overall treatment households. Interestingly, girls are found to attend school more than the boys in the treatment households (83.76% vs. 79.72), although this finding is not statistically significant. Despite girls are observed to achieve more completed grade years in the treatment households; boys are found to achieve less completed grading years compared to the overall control households.

5.1.2 Impact on Social Outcomes

Table 5.2 demonstrates the impacts of solar mini grid on social outcomes particularly on women. Social outcomes have been measured in terms of distance between home and toilet, access to electricity in the toilet and attacked on way towards the toilet in last one year. The average distance between home and toilet is significantly less in the overall treatment households (21.64 ft.) than that of the overall control households (25.13 ft.). On average, overall, more treatment households are found to have access to electricity in the toilet compared to the control households (i.e. 17.05% vs. 3.18%) and this finding is statistically significant. The striking evidence in our findings in terms of social outcomes is perhaps the percentage of women been attacked on way towards the toilet. On average, about 3.86% of the women respondents in the overall treatment households mentioned that they had been attacked on way towards the toilet. This finding has been significantly lower than the average female responses in the control households (i.e. 6.32%). This is crucial as the finding implies that adoption of solar mini grid significantly reduces violence on women and improves security, particularly of women.

Table 5.2: Social outcomes (for women)

Outcome Variable	SMG households			Non- SMG HHs			Diff.	p-value
	SMG	SMG+ SHS	Overall (Avg.)	Only SHS	Control	Overall (Avg.)		
Distance between home and toilet (ft)	23.18	20.15	21.64	23.82	27.19	25.13	-3.49	0.00
Access to electricity in the toilet (%)	8.55	25.49	17.05	5.01	0.28	3.18	13.87	0.00
Last one year attacked on way towards the toilet (%)	4.59	3.16	3.86	4.27	9.55	6.32	-2.46	0.02

Source: BIDS Survey (2018).

5.1.3 Impact on Welfare Outcomes

Table 5.3 illustrates the impact of solar mini grid adoption on key welfare outcomes such as per capita income (further disaggregated by farm and non-farm), per capita expenditure (disaggregated by food and non-food), per capita asset and total study time (differentiated by boys and girls) for both treatment and control households respectively. Our findings show that on average, per capita income has significantly increased for the overall treatment group (Tk. 51605.58) compared to the overall control group (Tk. 34636.88) consistent with previous literatures and our a-priori as well. This finding is also found to be consistent with per capita farm income (Tk. 4947.76 vs. Tk. 3262.58) and per capita non-farm income (Tk. 46657.82 vs. Tk. 31374.30) for both the overall treatment and control households respectively. Similarly, per capita expenditure has increased significantly for the overall treatment households than that of the control households (Tk. 39032.83 vs. Tk. 28596.97). The disaggregated results are also found to be consistent with the earlier findings i.e. food expenditure (Tk. 17850.20 vs. Tk. 15332.48) and non-food expenditure (Tk. 21182.63 vs. Tk. 13264.48) for both the overall SMG adopted and SMG non-adopted households respectively and the differences are statistically significant. The other welfare indicator i.e. per capita asset is also found to be significantly increased for the overall treatment group (Tk. 353786.80) compared to the overall control group (Tk. 123265.00). The total study time per day is found to be significantly increased in the overall treatment group compared to the overall control group (105.32 min. vs. 93.76 min.), also consistent with gender-differentiated (i.e. boys and girls) outcomes as described earlier.

Table 5.3: Welfare Outcomes

Outcome Variable (Taka)	SMG households			Non-SMG HHs			Diff.	p-value
	SMG	SMG+ SHS	Overall (Avg.)	Only SHS	Control	Overall (Avg.)		
Per capita income	38772.41	64010.99	51605.58	36608.69	31629.36	34636.88	16968.71	0.00
Per capita farm income	3228.83	6609.40	4947.76	4266.27	1731.70	3262.58	1685.18	0.02
Per capita non-farm income	35543.58	57401.59	46657.82	32342.43	29897.66	31374.30	15283.52	0.00
Per capita expenditure	29545.32	48204.09	39032.83	30795.27	25244.01	28596.97	10435.86	0.00
Per capita food expenditure	15890.04	19745.02	17850.20	16055.86	14229.15	15332.48	2517.72	0.00
Per capita non-food expenditure	13655.28	28459.07	21182.63	14739.41	11014.85	13264.48	7918.15	0.00
Per capita asset	258426.90	445968.00	353786.80	163399.00	62050.59	123265.00	230521.70	0.00
Study Time (min./day)								
Boys	94.22	115.69	105.64	96.43	87.91	93.19	12.45	0.00
Girls	98.36	111.02	104.95	97.29	89.30	94.29	10.67	0.00
Total Study Time	96.20	113.51	105.32	96.88	88.62	93.76	11.56	0.00

Source: BIDS Survey (2018).

5.4 Total electricity usage

As evident in Table 5.4, the total electricity usage in terms of electric and non-electric appliances/gadgets in the households. The survey findings suggest that on average, total electricity use per day is significantly higher in the overall treatment group compared to the overall control group (16.64 hours. vs. 9.39 hours) respectively. This finding is further found to be consistent with the increased amount of total watt power use per day in the overall treatment households (i.e. 58.08 WP) than that of the overall control households (i.e. 12.44 WP) and the difference is found to be statistically significant.

Table 5.4: Total Electricity Usage (Electric and non-electric appliances/gadgets)

Purposes	SMG households			Non-SMG HHs			Diff.	p-value
	SMG	SMG+ SHS	Overall (Avg.)	Only SHS	Control	Overall (Avg.)		
Total time usage (hour/day)	13.96	19.24	16.64	11.73	5.82	9.39	7.25	0.00
Total Watt Power use (day)	30.68	84.57	58.08	20.39	0.30	12.44	45.65	0.00

Source: BIDS Survey (2018).

5.5 Regression results

To establish the causal impact, we run several regressions. Our econometric model specification is as follows:

$$Y_{ij} = \beta + \alpha_1 SMG_{(1, 0)} + \alpha_2 X_{ij} + \alpha_3 V_j + \varepsilon_{ij} \qquad (1)$$

Where, Y_{ij} represents per capita income, per capita farm income, per capita non-farm income, per capita expenditure, per capita food expenditure, per capita non-food expenditure, per capita asset, study time of boys and girls for household i in village j; SMG indicates a dummy variable i.e. if the household is an SMG adopter = 1, 0 otherwise; X_{ij} denotes household-level characteristics (e.g. age, marital status, formal education, house ownership, land ownership, access to safe drinking water and sanitation); V_j indicates village-level characteristics which includes village population, households in village, village distance from district and upazila sadar, landless (below 0.5 acre), marginal land holder (0.5-1 acre), small land holder (1-2.5 acre), medium land holder (2.5-7.5 acre), large land holder (7.5+ acre), average daily wage (male), farm, non-farm, average daily wage (female), farm, non-farm, average daily wage (child), farm, non-farm etc. and ε_{ij} captures the error term.

Since the adoption of SMG electricity might have simultaneity biases, it is important to apply proper IV regressions. The IV regressions were run to assess the impact of solar mini-grid on per capita income and per capita expenditures (Table 5.5). We have used several instruments, such as Information from Solar Mini Grid Company, Information from village leader, Distance from mini grid station, Distance from mini grid pole and Peer (e.g. friends/neighbors) effect, which are expected to be associated with SMG adoption but not with outcome variables. Our diagnostic tests also qualify them as valid instruments.

We find that solar mini-grid electricity significantly increases per capita income, particularly per-capita non-farm income, which is about 27%. This is reasonable as many households started various businesses such as transport businesses using charged battery with the electricity, mobile phone service center etc. On the other hand, we find that access to solar mini-grid electricity increases all types of consumption (food and non-food) as well as assets. Therefore, solar mini-grid electricity enhances welfare of the households.

Next, we run similar IV regressions to assess the impact of solar mini-grid on study time (Table 5.6). We find that total study time and boys' study time has increased significantly by about 25% with access to electricity. However, we did not find the similar results for the girls' study time, which is consistent with previous results (Hossain et al., 2018).

Table 5.5 Impact of Solar Mini Grid on Household Welfare Outcomes (IV Regression Results)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
VARIABLES	Log Total income	Log Farm income	Log Non-farm income	Log Total expenditure	Log Food expenditure	Log Non-food expenditure	Log Total asset
SMG	0.220***	-0.253	0.273***	0.242***	0.101***	0.443***	0.597***
	(0.0743)	(0.368)	(0.0859)	(0.0417)	(0.0305)	(0.0653)	(0.102)
Age	0.00468***	0.0414***	0.00219	0.00250***	0.00150**	0.00412***	0.0173***
	(0.00163)	(0.00795)	(0.00187)	(0.000903)	(0.000659)	(0.00141)	(0.00220)
Marital status	-0.176**	1.524***	-0.249**	-0.111**	-0.0668*	-0.148**	-0.123
	(0.0868)	(0.422)	(0.1000)	(0.0479)	(0.0350)	(0.0750)	(0.117)
Formal education	0.218***	0.306	0.217***	0.190***	0.0951***	0.313***	0.469***
	(0.0419)	(0.205)	(0.0482)	(0.0233)	(0.0170)	(0.0365)	(0.0568)
House ownership	0.104**	2.003***	0.0315	0.0296	0.0382**	0.0197	1.188***
	(0.0470)	(0.231)	(0.0541)	(0.0262)	(0.0191)	(0.0411)	(0.0638)
Land ownership	0.000437***	0.00196***	0.000252***	0.000443***	0.000218***	0.000649***	0.00163***
	(6.10e-05)	(0.000301)	(7.03e-05)	(3.42e-05)	(2.50e-05)	(5.35e-05)	(8.32e-05)
Access to safe drinking water	-0.00665	-0.108	-0.00282	0.100***	0.0716***	0.137***	0.359***
	(0.0423)	(0.208)	(0.0488)	(0.0236)	(0.0172)	(0.0369)	(0.0574)
Access to sanitation	0.274***	1.435***	0.180**	0.0980**	0.0482	0.192***	0.655***
	(0.0794)	(0.392)	(0.0915)	(0.0445)	(0.0325)	(0.0697)	(0.108)
Total HH in village	0.000141**	-0.000178	0.000177**	3.04e-05	1.49e-05	7.92e-05	0.000268***
	(6.13e-05)	(0.000302)	(7.13e-05)	(3.43e-05)	(2.51e-05)	(5.38e-05)	(8.36e-05)
Total people in village	-2.65e-05***	7.11e-05*	-3.75e-05***	-4.72e-06	-4.70e-06	-6.98e-06	-1.57e-05
	(8.19e-06)	(4.04e-05)	(9.79e-06)	(4.59e-06)	(3.35e-06)	(7.19e-06)	(1.12e-05)
Landless	-0.0146	-0.163***	-0.00742	-0.0197***	-0.0171***	-0.0204*	-0.0408**
	(0.0125)	(0.0617)	(0.0144)	(0.00701)	(0.00512)	(0.0110)	(0.0171)
Landowner (marginal)	-0.0165	-0.189***	-0.00935	-0.0224***	-0.0217***	-0.0216*	-0.0442**
	(0.0140)	(0.0692)	(0.0162)	(0.00786)	(0.00574)	(0.0123)	(0.0191)
Landowner (small)	-0.0191	-0.188***	-0.00732	-0.0106	-0.0127**	-0.00723	-0.0176
	(0.0128)	(0.0632)	(0.0148)	(0.00717)	(0.00524)	(0.0112)	(0.0174)
Landowner (medium)	-0.00279	-0.156*	-0.00393	-0.0335***	-0.0324***	-0.0325*	-0.0641**
	(0.0191)	(0.0941)	(0.0220)	(0.0107)	(0.00780)	(0.0167)	(0.0260)
District	0.00555***	-0.0274***	0.00838***	0.00355***	0.00263***	0.00459***	-0.00761***
	(0.00150)	(0.00732)	(0.00172)	(0.000831)	(0.000607)	(0.00130)	(0.00202)
Upazila	-0.0120***	0.0184*	-0.0137***	-0.00709***	-0.00390***	-0.00955***	0.00624**
	(0.00193)	(0.00951)	(0.00222)	(0.00108)	(0.000788)	(0.00169)	(0.00263)
Male farm wage	-0.00118***	0.00106	-0.00129***	-0.000772***	-0.000173	-0.00116***	0.000340
	(0.000382)	(0.00187)	(0.000440)	(0.000212)	(0.000155)	(0.000332)	(0.000516)
Male non-farm wage	0.000343	-0.00754***	0.000449	0.000557***	-0.000122	0.00138***	-0.000267

	(0.000278)	(0.00137)	(0.000320)	(0.000155)	(0.000113)	(0.000243)	(0.000378)
Constant	11.56***	18.47***	10.96***	11.83***	11.38***	10.31***	12.27***
	(1.326)	(6.530)	(1.527)	(0.741)	(0.541)	(1.161)	(1.804)
Observations	1,604	1,623	1,603	1,623	1,623	1,623	1,623
R-squared	0.117	0.191	0.074	0.227	0.149	0.206	0.481
F-Statistics	14.16***	20.99***	9.8***	34.95***	18.63***	34.07***	90.82***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Underidentification test: X2	578.411***	578.223***	574.839***	578.223***	578.223***	578.223***	578.223***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Weak identification test	178.33	177.101	176.674	177.101	177.101	177.101	177.101
	(18.37)	(18.37)	(18.37)	(18.37)	(18.37)	(18.37)	(18.37)
Overidentification test: X2	16.891***	6.089	16.604***	25.288***	20.04***	21.989***	13.651*
	(0.002)	(0.1926)	(0.0023)	(0.0000)	(0.0005)	(0.0002)	(0.0085)
Endogeneity test: X2	22.728***	0.013	24.008***	77.118***	25.946***	94.175***	71.086***
	(0.0000)	(0.9083)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)

Source: Authors' calculations.

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

Table 5.6 Impact of Solar Mini Grid on Study Time

VARIABLES	Log Total study time	Log Boys study time	Log Girls study time
SMG	0.257**	0.246**	0.0261
	(0.116)	(0.122)	(0.131)
Age	0.0108***	0.00838***	0.00631**
	(0.00279)	(0.00309)	(0.00312)
Marital status	0.0452	-0.120	0.151
	(0.164)	(0.174)	(0.209)
Formal education	0.141**	0.0618	0.151**
	(0.0637)	(0.0709)	(0.0716)
House ownership	0.0357	0.0185	0.0353
	(0.0719)	(0.0814)	(0.0818)
Land ownership	0.000185**	0.000278***	7.03e-05
	(7.93e-05)	(8.58e-05)	(9.84e-05)
Access to safe drinking water	0.0171	-0.0563	0.0953
	(0.0637)	(0.0707)	(0.0719)
Access to sanitation	0.0695	0.303**	-0.192
	(0.133)	(0.148)	(0.155)
Total HH in village	0.000203**	0.000197**	8.23e-05
	(7.90e-05)	(8.62e-05)	(8.44e-05)
Total people in village	-1.44e-06	-3.68e-06	3.33e-06
	(9.96e-06)	(1.08e-05)	(1.10e-05)
Landless	0.284	0.0566	0.694*
	(0.342)	(0.355)	(0.409)
Landowner (marginal)	0.288	0.0594	0.703*
	(0.342)	(0.354)	(0.408)
Landowner (small)	0.292	0.0623	0.699*
	(0.343)	(0.356)	(0.410)
Landowner (medium)	0.286	0.0702	0.678*
	(0.337)	(0.349)	(0.404)
District	0.284	0.0496	0.710*
	(0.344)	(0.356)	(0.410)
Upazila	0.00245	0.00451	0.00105
	(0.00256)	(0.00290)	(0.00293)
Male farm wage	-0.000806	0.000686	-0.00670**
	(0.00277)	(0.00303)	(0.00315)
Male non-farm wage	-0.000568	-0.000242	-0.000625
	(0.000571)	(0.000659)	(0.000619)
SMG	0.00125***	0.00112**	0.000837*
	(0.000401)	(0.000465)	(0.000436)
Constant	-25.10	-2.679	-65.47
	(34.15)	(35.38)	(40.78)
Observations	798	544	516
R-squared	0.079	0.051	0.111
F-Statistics	4.18***	2.76***	3.28***
	(0.0000)	0.0001	(0.0000)
Underidentification test: X^2	278.086***	201.224***	178.47***
	(0.0000)	(0.0000)	(0.0000)
Weak identification test	82.798	61.052	52.029
	(18.37)	(18.37)	(18.37)
Overidentification test: X^2	4.048	0.484	5.916
	(0.3996)	(0.975)	(0.2055)
Endogeneity test: X^2	4.762**	14.602***	0.062
	(0.0291)	(0.0001)	(0.803)

Source: Authors' calculations.
Note: Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

CHAPTER 6: SUMMARY AND CONCLUSIONS

The study analyzes the impact of solar mini grid adoption (SMG) on households' income, asset, educational and social outcomes. Our survey results suggest that solar mini-grid facility provides electricity to mostly poor segment of the population who were left out from grid-electricity connection due to geographical difficulties of extending grid facilities. Access to solar mini-grid electricity not only provided better electricity in terms of reliability and lighting coverage compared to SHS, it also makes a positive impact on children's education, income generation, improvement of quality of life and safety and security.

In terms of the impact of solar mini grid adoption on key welfare outcomes, our findings show that on average, per capita income, expenditures and asset has significantly increased for the treatment group compared to the control group. We also find that though the total study time per day has increased by 12 minutes in the treatment group, it is statistically significant. Access to solar mini-grid electricity significantly increases per capita income, particularly per-capita non-farm income, which is about 27%. This is reasonable as many households started various businesses, such as transport businesses using charged battery with the electricity, mobile phone service center etc. On the other hand, we find that access to solar mini-grid electricity increases all types of consumption (food and non-food) as well as assets. Therefore, solar mini-grid electricity enhances welfare of the households. Regression results also show that total study time and boys' study time has increased significantly by about 25% with access to solar electricity. However, we did not find the similar results for the girls' study time, which is consistent with previous results (Hossain et al., 2018).

Nevertheless, one important benefit of solar electricity is that it provides access to environment-friendly clean energy. We estimate that solar mini-grid electricity saves consumption of Kerosene worth Tk.136 (price of 2 liter) for each of the beneficiary households per month. So far 7 mini-grid projects have successfully created access to low- emission electricity for almost 5000 rural households in Bangladesh. Thus, the program so far saves about Tk.8.16 million per year. The reduction in kerosene consumption contributes to a reduction in indoor air pollution and creates external positive benefit on the health of household members. The large number of subscribers under the 23 operational projects (12,298 as of July 2019) of IDCOL is expected to have greater impact on reduction of indoor air pollution.

However, tariff for SMG electricity is reasonably high, and therefore, initiatives should be taken to reduce this burden of electricity cost for sustainable welfare generation of the poorer households. Low cost financing solution through reducing interest rates, initiating green bonds and other instruments with proper policies of the government might make SMG electricity affordable to the poor.

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Appendix-I

Table A1: Electric and non-electric appliances/gadgets in the household

Appliance	Treatment			Control			Diff.	p-value
	MG	MG+ SHS	Overall (Avg.)	Only SHS	Control	Overall (Avg.)		
Tube light								
Average Number	0.04	1.93	1.00	2.07	0.00	1.25	-0.25	0.01
Total watt power (WP)	27.67	15.74	15.98	14.48	0.00	14.47	1.51	0.13
Average daily total use(hours)	3.45	3.52	3.52	4.03	0.00	4.03	-0.51	0.00
CFL bulb/ Energy saving bulb								
Average Number	0.32	0.57	0.45	0.08	0.00	0.05	0.40	0.00
Total watt power (WP)	14.25	40.56	32.09	7.50		7.50	24.59	0.05
Average daily total use(hours)	3.38	3.81	3.64	3.11		3.11	0.52	0.29
LED Bulb								
Average Number	3.14	3.88	3.51	1.31	0.00	0.79	2.72	0.00
Total watt power (WP)	18.15	22.89	20.51	13.85		13.85	6.66	0.00
Average daily total use(hours)	4.56	3.94	4.25	4.33		4.33	-0.09	0.44
Fan (Ceiling/pedestal/table)								
Average Number	1.45	2.45	1.96	1.02	0.00	0.62	1.35	0.00
Total watt power (WP)	62.39	107.08	92.38	36.21	0.00	36.43	55.95	0.00
Average daily total use(hours)	7.67	6.87	7.24	6.90	0.00	6.91	0.33	0.13
Charger Light								
Average Number	0.034	0.022	0.028	0.003	0.00	0.002	0.026	0.000
Total watt power (WP)	5.00	60.00	46.25	5.00		5.00	41.25	
Average daily total use(hours)	1.61	1.64	1.62	2.00		2.00	-0.38	
Television (BW)								
Average Number	0.004	0.033	0.019	0.007	0.00	0.004	0.015	0.003
Total watt power (WP)	12.00	12.00	12.00	12.00		12.00	0.00	
Average daily total use(hours)	3.00	2.13	2.22	2.50		2.50	-0.28	0.77
Television (Color)								
Average Number	0.04	0.11	0.08	0.01	0.00	0.01	0.07	0.00
Total watt power (WP)	70.00	54.33	57.00	70.00		70.00	-13.00	
Average daily total use(hours)	3.05	3.92	3.68	2.33		2.33	1.34	0.17
Television (LED/LCD/CRT)								
Average Number	0.02	0.10	0.06	0.01	0.00	0.01	0.05	0.00
Total watt power (WP)	40.00	54.31	53.29	50.00		50.00	3.29	0.90
Average daily total use(hours)	2.63	2.92	2.88	3.40		3.40	-0.52	0.58
Refrigerator/Freezer								
Average Number	0.02	0.14	.08	0	0	0.00	.08	0.00
Total watt power (WP)	75.25	145.00						
Average daily total use(hours)	13.36	18.17						
Mobile charger								
Average Number	1.76	2.33	2.05	1.63	1.03	1.39	0.66	0.00
Total watt power (WP)	2.67	1.36	1.78	1.09	-	0.95	0.82	0.14
Average daily total use(hours)	1.72	1.91	1.82	1.70	1.34	1.58	0.24	0.00

Appliance	Treatment			Control			Diff.	p-value
	MG	MG+ SHS	Overall (Avg.)	Only SHS	Control	Overall (Avg.)		
Charger light/ Solar lantern								
Average Number	0.18	0.27	0.22	0.13	0.03	0.09	0.13	0.00
Total watt power (WP)	11.00	5.85	7.88	6.40	-	5.36	2.52	0.57
Average daily total use(hours)	1.99	1.91	1.94	1.99	2.06	1.99	-0.05	0.73
Computer/Laptop								
Average Number	0.002	0.022	0.012	0.003	0.005	0.004	0.008	0.059
Total watt power (WP)		60.00						
Average daily total use(hours)	3.00	2.09	2.17	2.50	3.00	2.67	-0.50	0.60
Remote/calculator/toys								
Average Number	0	.03	.01	0	0	0	.01	0.00
Total watt power (WP)		1.00						
Average daily total use(hours)		2.61						
Car Battery								
Average Number	0.008	0.012	0.010	0.005	0.005	0.005	0.005	0.252
Total watt power (WP)								
Average daily total use(hours)	11.00	11.33	11.20	2.00	4.00	2.67	8.53	0.00
Kerosene wick								
Average Number	0.18	0.02	0.10	0.13	1.65	0.73	-0.63	0.00
Total watt power (WP)								
Average daily total use(hours)	1.09	2.44	1.25	1.40	3.68	3.39	-2.14	0.00
Kerosene hurricane lamps								
Average Number	0.022	0.004	0.013	0.015	0.293	0.125	-0.112	0.000
Total watt power (WP)								
Average daily total use(hours)	2.14	1.25	2.00	1.94	4.51	4.31	-2.31	0.00
Kerosene petromax lamps								
Average Number	0.006	0.000	0.003	0.002	0.015	0.007	-0.004	0.283
Total watt power (WP)								
Average daily total use(hours)	2.00		2.00	3.00	4.50	4.20	-2.20	0.03
Kerosene stove (traditional)								
Average Number				.003	0	.002	.002	0.317
Total watt power (WP)				2.00				
Average daily total use (hours)				3.00				
Kerosene stove (improved)								
Average Number	0	.002	.001	0	0	0	.001	0.318
Total watt power (WP)								
Average daily total use(hours)		1.00						
Others (specify)								
Average Number	0.006	0.041	0.024	0.002	0.003	0.002	0.022	0.000
Total watt power (WP)		31.00						
Average daily total use(hours)	8.33	3.83	4.42	1.00	2.00	1.50	2.92	0.60
Energy source used for these appliances								
Kerosene	4.59	0.49	2.21	3.42	58.86	20.12	-17.91	0.00
SMG	95.29	82.28	87.74	0.11	-	3.36	84.38	0.00
Storage/ car battery	0.00	0.31	0.18	0.00	0.25	0.07	0.11	0.26
SHS	0.00	41.69	24.18	96.53	-	76.07	-51.89	0.00
Generator	0.00	0.00	0.00	0.00	0.87	0.26	-0.26	0.00
Others	0.00	0.18	0.10	0.00	0.25	0.07	0.03	0.71

Source: BIDS Survey (2018).

Table A2: Housing and dwelling characteristics of the households

Categories	Treatment			Control			Diff.	p-value
	SMG	SMG+ SHS	Overall (Avg.)	Only SHS	Control	Overall (Avg.)		
Category of home ownership								
-Owned (%)	76.67	77.45	77.07	71.36	60.10	66.90	10.17	0.00
-Rented/leased (%)	7.71	12.75	10.27	10.76	13.38	11.80	-1.53	0.27
-No rent (%)	15.62	9.80	12.66	17.88	26.52	21.30	-8.64	0.00
Number of rooms (excluding the bathroom, storage and cowshed)	2.33	3.25	2.80	2.39	1.71	2.13	0.67	0.00
Value of dwelling land if own (in taka)	168401.40	294906.10	233124.8	170318.80	113800.10	150084.8	83039.98	0.00
Value of dwelling house if own (excluding the land) (in taka)	65260.00	170578.20	118972.3	57638.37	28625.38	46161.35	72810.95	0.00
Access to electricity (%)	100	100	100	100	0	60.40	39.60	0.00
Access to hygienic sanitation	90.26	90.20	90.23	90.07	80.81	86.40	3.83	0.01
Access to arsenic free Tube-well (%)	46.86	62.75	54.94	52.81	47.98	50.90	4.04	0.07
Distance of the latrine from HH (ft)	23.52	20.25	21.85842	23.69	27.05	25.021	-3.16	0.00
N	493	510	1003	604	396	1000		

Source: BIDS Survey (2018), (row percentages are used)

Table A3: Materials used for the main dwelling (%)

Material Type	Treatment			Control			Diff.	p-value
	SMG	SMG+ SHS	Overall (Avg.)	Only SHS	Control	Overall (Avg.)		
Floor								
Mud	91.68	61.57	76.37	93.71	97.98	95.40	-19.03	0.00
Timber	4.26	14.51	9.47	2.81	1.52	2.30	7.17	0.00
Brick/Cement	4.06	23.92	14.16	3.48	0.51	2.30	11.86	0.00
Walls								
Mud	9.13	3.33	6.18	13.25	15.15	14.00	-7.82	0.00
Bamboo/Thatched/Straw/Jute stick/Timber	4.46	2.94	3.69	3.15	11.11	6.30	-2.61	0.01
CI sheet (Tin)	80.53	81.76	81.16	79.30	72.73	76.70	4.46	0.01
Brick/Cement	5.88	11.96	8.97	4.30	1.01	3.00	5.97	0.00
Roof								
Bamboo/Thatched/Straw/ Jute stick/Timber/Brick/ Cement	1.42	3.73	2.59	1.66	2.02	1.8	0.79	0.01
CI sheet (Tin)	98.78	96.27	97.51	97.52	94.44	96.30	1.21	0.12
Total	493	510	1003	604	396	1000		

Source: BIDS Survey (2018).

Table A4: Attitude and perceptions towards solar mini-grid

List of perceptions	Treatment			Control			Diff.	p-value
	SMG	SMG+ SHS	Overall (Avg.)	Only SHS	Control	Overall (Avg.)		
Having electricity is important for my children's education								
Strongly agree	80.12	83.73	81.95	75.99	73.74	75.10	6.85	0.00
Agree	14.60	14.31	14.46	17.72	17.68	17.70	-3.24	0.05
Neutral	5.27	1.96	3.59	5.79	6.57	6.10	-2.51	0.01
Disagree/Strongly Disagree	0	0	0	0.5	2.02	1.1	-1.1	0.04
Because of good light, children have extended their studying time at nights								
Strongly agree	57.40	61.57	59.52	31.29	12.37	23.80	35.72	0.00
Agree	30.63	29.80	30.21	30.13	22.73	27.20	3.01	0.14
Neutral	10.95	7.25	9.07	34.27	43.18	37.80	-28.73	0.00
Disagree/Strongly Disagree	1.01	1.38	1.2	4.3	21.72	11.2	-10	0.05
Because of good light, we can study during the evening								
Strongly agree	54.16	57.06	55.63	27.32	10.35	20.60	35.03	0.00
Agree	34.48	33.53	34.00	32.78	16.67	26.40	7.60	0.00
Neutral	9.94	7.84	8.87	38.08	48.99	42.40	-33.53	0.00
Disagree/Strongly Disagree	1.42	1.57	1.5	1.82	23.99	10.6	-9.1	0.01
Reading is easy/comfortable with electric light compared to that with candles, kerosene lamps/lanterns								
Strongly agree	52.13	61.76	57.03	42.72	31.06	38.10	18.93	0.00
Agree	40.77	35.10	37.89	38.41	45.96	41.40	-3.51	0.11
Neutral	6.90	3.14	4.99	17.88	21.21	19.20	-14.21	0.00
Disagree/Strongly Disagree	0.2	0	0.1	0.99	1.77	1.3	-1.2	0
Because of electricity we are connected to the world information, news, etc.								
Strongly agree	21.50	27.65	24.63	12.25	11.11	11.80	12.83	0.00
Agree	39.55	40.39	39.98	18.87	9.09	15.00	24.98	0.00
Neutral	31.64	24.31	27.92	53.97	54.04	54.00	-26.08	0.00
Disagree/Strongly Disagree	7.3	7.65	7.48	14.9	25.75	19.2	-11.72	0.02
Electricity has made the inside of our household smoke-free								
Strongly agree	50.10	50.59	50.35	32.45	13.89	25.10	25.25	0.00
Agree	27.18	30.00	28.61	25.50	5.56	17.60	11.01	0.00
Neutral	5.48	6.08	5.78	22.35	36.11	27.80	-22.02	0.00
Disagree/Strongly Disagree	17.24	13.33	15.25	19.7	44.44	29.5	-14.25	0.00
SMG is reliable and beneficial								
Strongly agree	49.90	46.47	48.16	21.03	18.69	20.10	28.06	0.00
Agree	30.02	31.57	30.81	21.85	23.23	22.40	8.41	0.00
Neutral	6.09	5.88	5.98	48.68	48.99	48.80	-42.82	0.00
Disagree/Strongly Disagree	14	16.08	15.06	8.44	9.09	8.7	6.36	0.00
Electricity is benefiting our community through improved economic and enterprise development								
Strongly agree	32.05	31.76	31.90	18.21	13.13	16.20	15.70	0.00
Agree	53.55	51.96	52.74	43.71	40.91	42.60	10.14	0.00
Neutral	13.39	14.90	14.16	36.75	41.41	38.60	-24.44	0.00

List of perceptions	Treatment			Control			Diff.	p-value
	SMG	SMG+ SHS	Overall (Avg.)	Only SHS	Control	Overall (Avg.)		
Disagree/Strongly Disagree	1.01	1.37	1.2	1.32	4.55	2.6	-1.4	0.02
Expense related to Mini-grid electricity purchase is very high and a financial burden to our family								
Strongly agree	39.55	33.92	36.69	14.90	15.15	15.00	21.69	0.00
Agree	28.80	24.31	26.52	20.03	18.18	19.30	7.22	0.00
Neutral	10.34	14.90	12.66	53.15	55.81	54.20	-41.54	0.00
Disagree/Strongly Disagree	21.3	26.87	24.13	11.92	10.86	11.5	12.63	0.00
Electricity from Mini-Grid ensures night security								
Strongly agree	51.72	52.75	52.24	28.97	27.53	28.40	23.84	0.00
Agree	42.60	39.41	40.98	28.15	28.03	28.10	12.88	0.00
Neutral	4.67	5.29	4.99	41.39	43.94	42.40	-37.41	0.00
Disagree/Strongly Disagree	1.01	2.55	1.8	1.49	0.51	1.1	0.7	0.34

Source: BIDS Survey (2018).

Appendix-II

Gender Equality and Women Empowerment Aspects

It is expected that SMG adoption will have positive impact on various indicators of women empowerment in terms of income generation, which will have further impact on women's decision making in social affairs, economic affairs, personal autonomy etc.

Various indicators of women's mobility decisions show that the mini grid (treatment) and the non-mini grid (control) households do not possess any significant difference (Table 3.9). For example, a significant proportion of women involve in visiting parental home in the community or neighboring villages (57.63% vs. 59.10%), visiting friends and relative in the community or neighboring villages (50.75% vs. 53.10%), going to markets/banks/microfinance branches in the community or neighboring villages (31.01% vs. 33.30%) and going to district town (5.58% vs. 4.20%).

Table A5: Women's freedom of mobility (%)

Women's independent decision-making ability	Treatment			Control			Diff.	p-value
	SMG	SMG + SHS	Overall (Avg.)	Only SHS	Control	Overall (Avg.)		
Visiting parental home in the community or neighboring villages	58.62	56.67	57.63	57.78	61.11	59.10	-1.47	0.50
Visiting friends and relative in the community or neighboring villages	50.71	50.78	50.75	52.32	54.29	53.10	-2.35	0.29
Going to markets/banks/microfinance branches in the community or neighboring villages	27.38	34.51	31.01	31.79	35.61	33.30	-2.29	0.27
Going to district town	5.07	6.08	5.58	3.64	5.05	4.20	1.38	0.15
Going to Dhaka city	1.42	3.53	2.49	0.83	1.77	1.20	1.29	0.03

Source: BIDS Survey (2018).

Nevertheless, the overall treatment respondents enjoyed significantly more freedom in terms of independent decision-making towards going to the urban capital city of Dhaka compared to the overall control respondents (2.49% vs. 1.20%). Also, treatment household women appear to have a higher say about the decision of having children compared to the control household women (Table 3.10).

Table A6: Women's decisions in household and social affairs

Women's independent decision-making ability	Treatment			Control			Diff.	p-value
	SMG	SMG+ SHS	Overall (Avg.)	Only SHS	Control	Overall (Avg.)		
Having children	1.42	0.78	1.10	0.17	0.76	0.40	0.70	0.07
Children's education	5.07	4.51	4.79	3.31	5.30	4.10	0.69	0.46
Children's healthcare/treatment	6.29	5.49	5.88	5.46	6.57	5.90	-0.02	0.99
Own healthcare/treatment	27.99	21.37	24.63	25.17	26.01	25.50	-0.87	0.65
Children's marriage	2.64	1.37	1.99	1.32	3.79	2.30	-0.31	0.64

Source: BIDS Survey (2018).

The findings revealed that around 24.63% of the overall treatment households can take decisions regarding their own healthcare/treatment compared to around 25.50% of the overall control households, albeit the difference is not statistically significant. This information has been followed by non-significant differentials on factors such as Children's healthcare/treatment (5.88% vs. 5.90%), Children's education (4.79% vs. 4.10%), Children's marriage (1.99% vs. 2.30%) and decision in having children (1.10% vs. 0.40%) for mini grid and non-mini grid households respectively.

Final Report-Part II

Impact Assessment of Solar Irrigation Program of IDCOL

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SUBMITTED TO:

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EXECUTIVE SUMMARY

Solar-powered irrigation systems are innovative and environment friendly solutions for agro-based economies like Bangladesh with reduction in fossil fuel dependency and grid electricity demand during irrigation seasons. Since 1971, Bangladesh has been able to increase its rice production three-fold, mostly due to mechanization in agriculture, conducive policy environment and increasing irrigation facilities. In recent times, the country has stepped into solar-powered irrigation technology which opens up a new avenue in agricultural production with increased efficiency and reliability in irrigation, enhanced crop production and food security to a greater extent. The Infrastructure Development Company Limited (IDCOL) has approved 1,429 solar irrigation pumps up to December 2018 and has set up a target of installing 50,000 solar irrigation pumps by 2025. The objective of this impact assessment study is to estimate the socio-economic benefits of solar irrigation compared to the non-solar based irrigation used in selected locations.

Our findings regarding the impact of solar irrigation show that farmers who are using solar irrigation (treatment) had harvested in significantly higher number of plots (3 vs 2.7 plots in Kharif-2 and 3.17 vs 2.8 plots in Rabi) and higher areas of land (1.35 vs 1.26 acre in Kharif-2 and 1.4 vs 1.3 acre in Rabi) compared to non-solar irrigation user group. We further looked at the impacts of solar irrigation on adequacy of water and cost of production. Our regression results suggest that the solar-powered irrigation provides greater access and reliability to meet the adequacy of water used for irrigation more efficiently. It is also found to reduce the cost of production marginally though the reduction of cost appears to be insignificant.

Based on diesel use per acre of land, we have estimated carbon emission by different types of pumps based on their longevity. Our estimation results suggest that with the increase in age of the diesel pumps, their carbon emission also increases. On average the diesel pumps emit 7.5 Kg Carbon Dioxide among the three seasons amassing 22.3484 Kg per acre over the course of a year.

Overall, solar-powered irrigation provides opportunity to irrigate a higher amount of land due to its beneficial aspects such as low cost, low wastage of water, and reliability, and consequently it also contributes to a higher amount of return from harvesting. In addition, it saves carbon emission and therefore contributes to reducing air pollution. During off-season, solar electricity generated from the solar irrigation projects is used for various other purposes. Therefore, to harness greater benefit for the farmers; more awareness building efforts are required in this regard along with dynamic price adjustments in irrigation related equipment as well. Environmental aspects, particularly use of deep surface water has to be contained. Finally, as the results are drawn from a cross-section survey data, more rigorous analysis could be done by making a panel of baseline and follow up data.

CHAPTER 1: INTRODUCTION

Bangladesh, being a lower-middle income country of over 160 million population, has achieved a very impressive economic growth at a rate over 6 percent in the last decade. Once dubbed as a basket case, the country has made an impressive progress in many sectors including agriculture. Since its independence in 1971, Bangladesh has been able to increase its rice production three-fold, thanks to mechanization in agriculture, conducive policy environment and increasing irrigation facilities. Now the country fed about 160 million people with its own crop production. Diversification of crops, use of high yield variety and use of land all the year round due to availability of irrigation facilities are some of the factors that contributed to almost self-sufficiency in rice production. Mainly irrigation is done using diesel pumps and grid electricity wherever it is available though it is fully reliable due to power outage. Government provides subsidies on biofuels that helped farmers to use irrigation at affordable prices. In recent times, the country has stepped into solar-powered irrigation technology, which opened up a new avenue in agricultural production mainly some of its advantages, such as efficiency and reliability in irrigation, enhanced crop production and ensuring food security at a greater extent.

Solar-powered irrigation systems are innovative and environment friendly solution for the agro-based economy of Bangladesh. The program intends to provide irrigation facility to rural off-grid areas. Solar irrigation systems reduce dependency on fossil fuel and demand for electricity from national grid in irrigation seasons. The program also reduces carbon emission and at the same time saves millions in foreign currency. Given the immense potential the program aims to install solar PV-based irrigation systems in areas where there are possibilities to produce three types of crops throughout the year, all the while staying safe from flooding, arsenic contamination and saline water. IDCOL has now set a target of installing 50,000 solar irrigation pumps by 2025. Up to December 2018, IDCOL has approved 1,429 solar irrigation pumps of which 1,186 are already in operation with a cumulative capacity of about 26.59 MWp. The remaining pumps are expected to come into operation shortly. The World Bank, KfW, GPOBA, JICA, USAID, ADB and BCCRF are supporting this initiative.

Solar irrigation system is an attractive alternative for traditional irrigation practices in developing countries, especially, Asian and African countries, keeping in view, the huge solar potential and the fact that significant rural population lives in remote areas which requires water for irrigation of crops. Chandel, Naik and Chandel (2015) identified solar-powered pumps as reliable and economically viable alternative to electric and diesel water pumps for irrigation of agriculture crops, but, the large installation costs of solar water pumps would require more incentives from the government to make the technology more attractive. Kelly et al (2010) found solar-powered irrigation systems both technically and economically feasible when compared to life cycle costs of diesel and grid-based irrigation systems. Khan, Sarkar and Islam (2013) conducted a feasibility analysis on the use of solar pumps for purpose of irrigation in Bangladesh. They concluded that solar pumps are more profitable for the period of 5 or more years and investment on solar pumps is less risky than diesel engine operated pumps.

Several studies suggest that solar irrigation systems bring forth economic benefits and also have positive impacts on environment and nutrition. Alaofe, Burney, Naylor and Taren (2016) conducted a study in Northern Benin and their findings suggested that solar-powered drip irrigation enhances diversity in crop production as well as dietary habits, thus, benefits both economically and nutrition wise. Burney et al (2010) also found that solar-powered irrigation increased food security. Suman (2018) constructed a report on the impacts of solar irrigation pumps program in Andhra Pradesh and Chhattisgarh states of India. The report suggested that implementation of solar-powered irrigation system has grossly increased the income of the farmers. It has also reduced the cost of irrigation and wastage of water and has caused a change in cropping pattern in some areas. Another interesting finding in the report was that due to the usage of the solar-powered irrigation system, the pressure on general electrical grid has lowered, resulting export of surplus power to the grid. It has also increased both the quality and quantity of the crops. Garg (2018) investigated the potential in solar-powered irrigation in India and pointed that implementation of solar-power irrigation systems can lead to greater economic well-being by reducing costs incurred for use of coal and diesel for irrigation and also can relax the burden of agricultural electricity subsidy from the government to some extent. Besides, it would also result in a significant amount of forex savings in the process.

Solar irrigation systems are slowly coming to prominence in terms of usage in Bangladesh too. World Bank (2015) reported that solar-powered pumps have reduced irrigation costs in Bangladesh. Islam, Sarker and Ghosh (2017) suggested that solar irrigation may be an alternative way to increase production of crops without creating extra pressure on grid power or diesel fuel, and also can help to keep the environment clean. They also found it to be cost effective and better suited for sustainable development in agriculture.

1.1 Objective of the Study

The objective of this study is to carry out household surveys to estimate the socio-economic benefits of Renewable Energy Technology (RET) systems under the Rural Electrification and Renewable Energy Development (RERED) project, in particular solar irrigation project of IDCOL.

1.2 Scope of the Study

The scope of the impact assessment study on solar irrigation project includes information collection on basic household characteristics, various sources of irrigation, energy consumption pattern in various irrigation modes, irrigation costs and the impact of solar irrigation on agricultural production through structured questionnaires. A community survey has also been carried out in respective areas where household surveys were conducted. An additional questionnaire has also been administered on the solar and diesel irrigation operators covering their experience, education, investment, coverage, sales, profit etc.

1.3 An Overview of IDCOL's SIPs

Solar irrigation systems are innovative and environment friendly solution for the agro-based economies. The solar irrigation program in Bangladesh has been implemented by the Infrastructure Development Company Limited (IDCOL), a public non-bank financial institution. The program intends to provide irrigation facility to rural off-grid areas. Solar irrigation systems reduce dependency on fossil fuel and demand for electricity from national grid in irrigation seasons. The program also reduces carbon emission and at the same time and saves millions in foreign currency. Given the immense potential the program aims to install solar PV-based irrigation systems in areas where there are possibilities to produce crops throughout the year, all the while staying safe from flooding, arsenic contamination and saline water. To work towards this end, IDCOL has set a target of installing 50,000 solar irrigation pumps by 2025. Up to December 2018, IDCOL has approved 1,429 solar irrigation pumps of which 1,186 are already in operation with a cumulative capacity of about 26.59 MWp. The remaining pumps are expected to come into operation shortly. The World Bank, KfW, GPOBA, JICA, USAID, ADB and BCCRF are supporting this initiative.

The SIP of IDCOL has taken multi-prong approaches that makes it more economically viable and innovative. Apart from ownership financing model, it includes capacity building of farmers, environment and social screening as well as options for using excess electricity for other purposes.

1.3.1 Financing Model

Similar to 'fee-for-service model', IDCOL finances the project under 'ownership model' based on debt, grant and equity ratio of 35%:50%:15%. The equity portion comes from the down payment (12%) of the farmers and partner organization's (PO's) own source (8%). The terms and conditions of the loan from IDCOL to PO are the same as the 'fee-for-service' model. The financing mechanism of a pump under 'ownership model' is shown below:

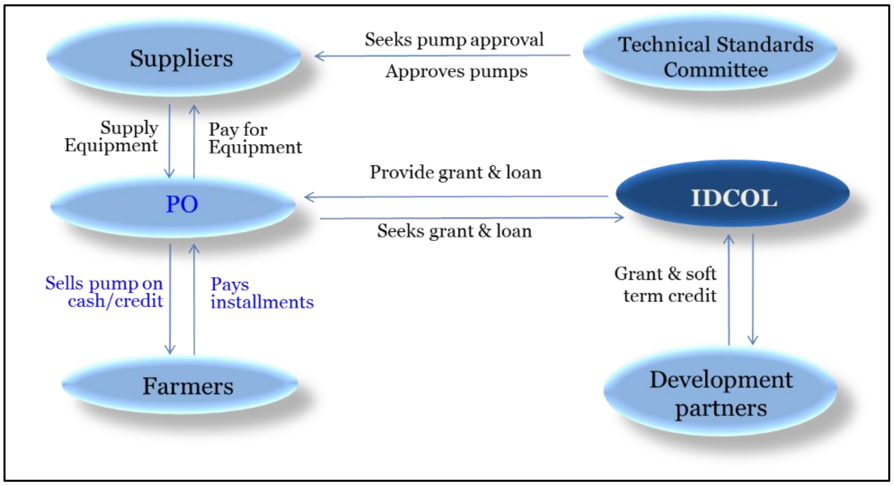
Table 1.1: Financing structure under 'ownership model'

	Amount in USD
Pump price without Subsidy [a]	13,271
Grant support (50%) [b]	6,635
Price to farmer [c = a –b]	6,635
Down-payment by farmer (30% of c or 15% of a) [d]	1,991
Loan from PO to farmer [e = c –d]	4,645
IDCOL loan to PO (35% of a) [f]	4,645

Source: IDCOL

Notably, the PO is expected to extend loan to farmers for a term of 5 years whereas IDCOL's loan to PO will be for 8 years. The average installment for investor will be USD 2,640 per year whereas the yearly savings in diesel cost for investor will be about USD 2,655. Notably, the investor remains in break-even point during the repayment period of 5 years but they will be benefited once the loan is fully repaid. Any private limited company/NGO/MFI is eligible to obtain financing from IDCOL for installing solar irrigation pumps provided their financial strength to spend required equity in the project, experience in similar nature of activities etc. are deemed to be suitable to IDCOL.

Figure 1.1: 'Ownership model' structure under IDCOL solar irrigation projects



Source: IDCOL

1.3.2 Use of Excess Electricity

During off-season, excess electricity generated by solar-powered pumps are used for several purposes:

- Excess electricity of some pumps is supplied to households
- Electricity is also used for activities like running oil press, producing hollow bricks
- Farmers now have extra time to do other activities for additional income.

Source: IDCOL

1.3.3 Environment and Social Screening

It is important to take extra caution against any environmental concerns that are caused by SIPs. Therefore, IDCOL sets a guideline on environment-related aspects. Arsenic contamination in water is tested in different terms of project life. Sponsors submit arsenic test results from DPHE prior fund disbursement. Periodic water level data is collected and checked for water depletion. Training on environmental and social safe guarding aspects.

1.3.4 Solar Irrigation Pump - Capacity Building

To increase the benefits of SIPs, IDCOL initiated several capacity-building training programs for both farmers and sponsors. A list of such training programs and attendees is given below.

Table 1.2: List of Trainings

SL	Type of Training	Topics covered	Number of Training
1	Training of Trainers	Site selection, project implementation, crop and water management, new cultivation techniques	5
2	Farmers' Training	Crop variety, fertilizer management, pest control, alternative wetting and drying (AWD), seed preservation	212
3	Demonstration of high yield variety for Farmers	Introducing a target plot with a new high yield variety of crop and showcasing the difference of yield	128
4	Training of Pump Supervisors	Operation management, Crop and Water management and revenue collection	27
5	Training for Pump Operators	Crop and water management, land mapping and irrigation scheduling	33
6	Technical Training for Suppliers	Project designing, trouble identification and on field troubleshooting techniques	2

Source: IDCOL

1.4 Organization of the Report

The report has been organized as follows: Chapter 2 clarifies the survey design methodology while the basic characteristics of the sample households have been described in Chapter 3. Chapter 4 analyzes various aspects of solar irrigation and crop production. Chapter 5 provides summary and conclusions.

CHAPTER 2: METHODS AND APPROACHES

2.1 Sampling Design

The IDCOL has determined the size of the sample for all the four components in the ToR. Though the sample size has been determined by IDCOL, its basis can be justified scientifically as follows.

The sampling theory provides the minimum required sample size determination formula for estimating proportion in large size population as follows:

$$n = z^2{}_{\alpha/2} \frac{p(1-p)}{d^2} \times f$$

where, p is the proportion of the required characteristics in the population based on hypothesis rather than observed facts, $z_{\alpha/2}$ the value of the standardized percentile allowing α probability of bad samples, d the allowable margin of error and $f$is the design effect used for complex surveys using multi-stage cluster sampling.

Conventionally, α can be taken as 0.05 and f can be taken as 1.5 to 2.0 for most socio-economic surveys in Bangladesh. For example, the solar irrigation pumps are new to many of the households, so theoretically, $p = 0.5$ gives the safest sample size since in this case $p(1-p)$ takes the highest value. A common choice for the value of the allowable margin of error is$d = 0.0025$. With $f = 2$ and considering anticipated non-responsive rate at 5% the above formula gives total sample size (household) to be is 768. Considering the same number of sample households from the control areas, we finally decided to collect samples for the solar irrigation interventions as follows.

The total sample size taken consisted of 1000 households (500 treatment households; 500 control households). The division-wise survey data depicts that majority of the treatment and control groups were selected from Khulna (52%), followed by Rangpur (38%). The latter shares of respondents were chosen from Dhaka (2%), Chittagong (2%) and Rajshahi (6%).

Table 2.1: Incidence of Solar irrigation pump adoption by divisions

Division	Treatment (%)	Control (%)
Dhaka	2	2
Chittagong	2	2
Rajshahi	6	6
Khulna	52	52
Rangpur	38	38
N	500	500

Source: BIDS Survey (2018).

2.2 Community survey

In addition to household survey, community survey was conducted in both treatment and control areas. The community surveys use separate questionnaires for each of the interventions even if communities overlap among interventions. Community survey included basic village characteristics, access to various infrastructures, IGA activities, price of alternate fuels and consumers goods, etc. The sample size for community surveys has been decided upon consultation with IDCOL. In particular, one community survey was conducted from each of the villages where household survey was conducted. In total 49 treatment and 50 control village questionnaire survey were conducted.

2.3 Pump owner Survey

A pump owner survey was also conducted in both treatment and control areas to understand various aspects of irrigation. The sample size for pump owner has been decided upon consultation with IDCOL. Overall, a total of 102 pump owners were surveyed where 51 pump owners were inquired from both treatment and control areas.

2.4 Development of Instrument

2.4.1 Reconnaissance Survey

Before developing the questionnaire for the solar irrigation survey, the IDCOL consultant and BIDS research team made a visit to Dhamrai where solar irrigation pumps have already been installed. The purpose of the survey was to see the possible changes that are being made in the area as well as coverage of irrigation pumps. The team also got a first-hand experience on pricing and other administrative aspects of solar pumps and characteristics of the beneficiary households.

2.4.2 Instruments

Both structured and semi-structured questions were incorporated in the questionnaires designed for both household and enterprise survey. The questions incorporated in the questionnaires were based on the objectives of the study. In addition, while designing the questionnaire, similar types of studies conducted in Bangladesh and outside Bangladesh were reviewed and also consulted with the Consultant of the IDCOL. Three modules of questionnaires were designed for household, community and POs.

Table 2.2: Key Issues in Specific Modules

Component	Specific Modules	Community Survey
Solar Irrigation pumps	- Household characteristics such as head's gender, age, education, household structure, sanitation etc. -Demographics of household member -Assets (Land, and non-land) -Education -Household income (**in details**) -Household expenditure (**in details**) -Time used for women and children -Attitude and opinion -Decision making in the household -Pump usage	-Basic village characteristics -access to various infrastructures -IGA activities - price of alternate fuels and - consumers goods

2.5 Mobilization of Team

Formation of the survey team is the first step towards survey implementation. Team members have been hired based on their skills and experience in various aspects of the survey implementation process and a thorough knowledge of local and country-specific context. A database of professional enumerators and supervisors of about 50 with five years and more experience mostly in rural area surveys nationwide was reviewed for selection. From the database, 2 teams were formed consisting of 5 members including one supervisor in each of the team for the Solar Irrigation surveys.

The supervisors and enumerators were recruited on the basis of their previous experiences on data collection and supervision. Minimum education qualification was graduate from social sciences or any other relevant subjects. For the supervisors, it was required to have at least five years of experience in field supervision activities. Supervisors were given the responsibility to supervise, coordinate, monitor and ensure validity of data collection.

Also a data entry specialist and 10 data entry operators were recruited for entry, cleaning and processing of survey data. Finally, research team was appointed with the responsibility to ensure the overall success of the survey activities and data integrity. Table 2.3 highlights the responsibilities of various team members.

Table 2.3: Major Roles and Responsibilities of the Team Members

Team member(s)	Major roles
Research Team	• Ensures overall success of the data collection activities. • Participates in survey instrument development and recruitment of qualified enumerators • Leads interviewer training, and development of training materials. • Coordinate and synchronizes data collection and data entry efforts to finish them in a timely and efficient manner. • Is in charge of drafting the survey report.
Field Supervisors	• Explain the project to, and seek cooperation from, the community/local leaders of the selected villages. • Arrange interview appointments with households for the field enumerators with the help of village leaders. • Assign interviewing assignments to field enumerators, help them locate sample households, and manage field work . • Ensure collection and accuracy of data by monitoring field interviews, and reviewing completed questionnaires submitted by the field interviewers. • Conduct enterprise survey • Conduct community survey.
Field Enumerators	• Locate households and conduct surveys. • Ensure the accuracy and completeness of the collected data. • Consult with their supervisors to resolve any confusion and survey related issues as opposed to making decisions on their own. • Are prepared to revisit households if any missing or incomplete items are discovered in the questionnaires.
Data Entry Operators	• Enter data into the computer using standard statistical software • Validate entered data.
Data Cleaning and Estimation	• Clean the data to ensure internal consistency. • Derive estimates of descriptive statistics and conduct the tests of differences wherever applicable.

2.6 Training and Quality Control Measures

A two day-long extensive training program for the surveys were conducted for the preliminary selected enumerators on the use of questionnaire. They were given adequate knowledge about RETs as well as selection of the respondents. Moreover, they were given instructions on how to collect various information from the households and enterprises. After the training, a **field-testing** of the questionnaire was done in two villages in Dhamrai. All the selected enumerators and supervisors were participated in the field-testing process.

2.7 Pretesting the Survey Instruments

Before administering each of the four surveys, pre-testing of the questionnaires was conducted. The objective of pretesting is to test the questionnaires and the overall preparedness of the survey team in conducting the actual survey. More specifically, pre-testing helps to identify if there is any problem in the questionnaire in terms of its language, logic and sequence. It is important to test whether a question, in the way it is phrased, is able to elicit the right response from the respondent. Pre-test gives a good opportunity to verify that. Also questions sequenced in right order (with proper skip pattern) and logic is likely to be answered more accurately than when they are not. Furthermore, pretesting ensures that the codes of close-ended questions are as exhaustive as possible; in particular, they take into account all the possibilities that are relevant to the country and local context. Moreover, pretesting provides the survey team personnel an opportunity to determine the expected duration for a household interview, and on that basis, the total time duration for conducting the whole survey can be estimated. Pretesting also provided the survey team an opportunity to evaluate the logistics and administration for the actual survey.

The pre-testing process was completed in two phases which are described below.

2.8 Preparation of the Survey Team

All the selected enumerators and supervisors had participated in the pre-testing process. Ideally, pre-testing is done in places away from the actual survey locations having similar conditions to actual survey areas. Considering the similarity of the households in actual survey areas, pre-testing was done two villages in Dhamrai upazila of Dhaka. The reason for selecting this district is that Solar irrigation pumps are available in in this area.

2.9 Administering Pretesting Interviews

Households selected for the pretesting were different from the ones selected for the actual surveys to ensure that pretesting does not influence or bias the households during the actual interviews. The survey team was provided vehicles for their transport to the specific villages, and they were equipped with necessary supplies as they would have been during the actual surveys, such as, the questionnaires, necessary authorization letters, and stationery. The BIDS representatives went to the villages to monitor pretesting interviews. Activities during the pretesting were including:

i. Carry out the interviews in entirety;

ii. Time calculation for each interview accurately, and make note of questions that take more than expected time;

iii. Check the questions for their logic, sequence and phrasing, and make note of questions that seem to confuse the respondents, make them hesitate or sensitive. Especially, all types of non-response should be carefully noted and distinguished, such as, “Do not know”, “Refuse to answer”, etc.; and

iv. Make note of categorical questions where the responses are outside the range of listed responses.

Pretesting for Solar irrigation pumps was done in the Dhamrai upazila of Dhaka. The details of the pre-testing are given in Table 2.4.

Table 2.4: Information on Pre-Testing Survey Instruments

RETs	Pre-testing dates	No. of treatment HHs interviewed	No. of control HHs interviewed	Village/community survey	Pump owner survey	Name of villages/districts
Solar Irrigation pumps	06/09/2018	8	8	1	2 (1 control and 1 treatment)	Village: Rohertek (Treatment), Rowali (Control) Union- Shoyapur, Upazila- Dhamrai, District- Dhaka

CHAPTER 3: BACKGROUND CHARACTERISTICS OF SAMPLE HOUSEHOLDS

This chapter highlights the socio-demographic characteristics, level of education, employment and occupation pattern, access to housing, water and sanitation, asset holdings, income, expenditure and agricultural land use patterns, which are important to draw valid inferences on the impact analysis. Moreover, it will provide idea about the balance of characteristics between treatment and control households.

3.1 Demographic Characteristics of the Households

This section illustrates the demographic characteristics of the sample households comparing households that adopted solar irrigation to those households that did not (Table 3.1). The average age of the household members is around 31 years for both the treatment and control groups, while the sex ratio (male: female) is not significantly different between them, demonstrating an overall higher number of males in the households than females for both groups. Proportion of respondents who are currently married is around 59% in both groups, followed by the proportion of those not currently or never married is around 39% for both treatment and control groups. Household size for the treatment and control groups is found to vary slightly (4.45 vs 4.29), implying marginally significant differences in the pattern of household sizes for the two groups. Female-headed households constitute a meager proportion (0.60 vs. 0.40) of the households in both the treatment and control groups. Overall, both treatment and control groups are found to be quite similar in terms of the aforementioned demographic characteristics.

Table 3.1: Demographic characteristics of the households

	Treatment	Control	Diff.	p-value
Sex ratio	1.44	1.41	0.03	0.61
Age (Years) (Avg.)	30.83	30.59	0.24	0.70
Married (%)	58.70	59.35	-0.65	0.83
Not currently married/never married (%)	38.46	38.64	-0.18	0.95
Proportion of female headed HH (%)	0.60	0.40	0.20	0.65
Household Size	4.45	4.29	.16	0.09

Source: BIDS Survey (2018).

3.2 Education and Literacy

This section demonstrates the level of education for respondents aged five and above for households in both treatment and control groups (Table 3.2). Around 52.1% of the household members in the treatment group have undergone less than 10 years of schooling, compared to a similar proportion for respondents in the control group (54.4%), with primary school completion noticeably higher than secondary school completion for both groups. Household members pursuing tertiary level of education is considerably low for both groups, but the proportion is higher for households in the treatment group compared to the control group (5.11% vs 3.98%), although not significantly. Religious schools and madrasa education constitute a relatively low proportion of households in both the treatment and control groups (0.56% vs. 0.89%).

Table 3.2: Years of schooling completed (%)

Schooling completed	Treatment	Control	Diff.	p-value
Never went to school	26.85	26.00	0.85	0.76
Class I to Class V	28.08	31.71	-3.63	0.21
Class VI to Class IX	24.01	22.70	1.30	0.63
SSC Level	8.59	8.17	0.42	0.81
HSC Level	4.06	4.46	-0.39	0.76
Trade course	0.05	0.00	0.05	0.62
Religious schools/madrasa	0.56	0.89	-0.33	0.54
Undergraduate to Post Graduate	5.11	3.98	1.13	0.39
Total N	500	500		

Source: BIDS Survey (2018).

3.3 Labor Force and Employment Status

This section demonstrates the different sectors in which the household heads of the treatment and control groups are employed (Table 3.3). As expected, most of the households head are self-employed in agriculture sector in both treatment and control groups (78.8% vs. 76.00%) which is followed by business (9.2% vs. 6.8%), wage laborers in agriculture (4.8% vs. 6.6%).

Table 3.3: Employment category of those who are employed (%)

Employment category (%)	Treatment	Control	Diff.	p-value
Wage laborers in agriculture	4.80	6.60	-1.80	0.22
Wage laborers in non-agriculture	0.40	1.20	-0.80	0.16
Salaried employee	2.60	3.00	-0.40	0.70
Self-employed in agriculture	78.80	76.00	2.80	0.29
Self-employed in non-agriculture	0.40	0.60	-0.20	0.65
Transport owner/Business	1.20	1.80	-0.60	0.44
Carpenter/Meissonier/Weaver	0.80	0.80	0.00	1.00
Business	9.20	6.80	2.40	0.16
Self-employed professionals	1.60	0.00	-1.60	0.00
Other self-employment	0.20	0.40	-0.20	0.56
Total	500	500		

Source: BIDS Survey (2018).

3.4 Housing, Water, Sanitation and Electricity

3.4.1 Housing

This section illustrates the housing and dwelling characteristics of households between the treatment and control groups (Table 3.4). Most of the households (98.80% vs. 99.40%) in both the groups dwell in their own houses. The average number of rooms (excluding the bathroom, storage and cowshed) in each household is roughly the same for both groups (2.74% vs. 2.71%). The value of the land the household is dwelling on and the house owned is higher, in absolute terms, for those in the treatment group, albeit not significantly for the value of the house. Similar pattern could also be observed in terms of households' access to arsenic free tube-well (86.20% vs. 85.80%) and hygienic sanitation (79.80% vs. 78.80%) for both the treatment and control groups respectively.

Table 3.4: Housing and dwelling characteristics of the households

Categories	**Treatment**	**Control**	**Diff.**	**p-value**
Category of home ownership (%)				
Owned	98.80	99.40	-0.60	0.32
No rent	1.20	0.60	0.60	0.32
Number of rooms (excluding the bathroom, storage and cowshed)	2.74	2.71	0.02	0.73
Value of dwelling land (in taka)	403726.3	363975.4	39750.91	0.09
Value of dwelling house (excluding the land) (in taka)	107014.1	95427.86	11586.23	0.14
Access to arsenic free Tube-well	86.20	85.80	0.40	0.86
Access to hygienic sanitation	79.80	78.80	1.00	0.70

Source: BIDS Survey (2018).

Table 3.5 presents data on the materials used for construction of the main dwelling of the sample households. For floors, mud is the most widely used material for both treatment and control group i.e. 71.20% vs. 72.60% respectively. For walls, brick/cement is used by a significantly higher proportion of households in the treatment group (63.40%) than the control group (53.60%). However, the control group use CI sheet (Tin) at a significantly higher percentage (25.60%) than the treatment group (20%). For construction of roofs, CI Sheet (Tin) is used by a significantly higher percentage of households in the control group (90.60%) followed by 87.2% in the treatment group.

Table 3.5: Materials used for the main dwelling (%)

Material Type	Treatment	Control	Diff.	p-value
Floor				
Mud	71.20	72.60	-1.40	0.62
Brick/Cement	28.80	27.40	1.40	0.62
Walls				
Mud	11.80	15.20	-3.40	0.12
Bamboo/Thatched/Straw/Jute stick/Timber	4.80	5.60	-0.80	0.57
CI sheet (Tin)	20.00	25.60	-5.60	0.03
Brick/Cement	63.40	53.60	9.80	0.00
Roof				
Bamboo/Thatched/Straw/Jute stick/Timber/ Tally	1.00	0.00	1.00	0.03
CI sheet (Tin)	87.20	90.60	-3.40	0.09
Brick/Cement	11.80	9.40	2.40	0.22
Total	500	500		

Source: BIDS Survey (2018).

3.4.2 Access to Electricity

This section exhibits the access to different sources of electricity of household members in the treatment and control groups (Table 3.6). On average, around 94% of households have access to electricity in both groups (95.60% vs. 93.60%), although the proportion is slightly higher for households in the treatment group. The major source of electricity for the households is minigrid/grid i.e. 95.19% vs. 96.15% for treatment and control group respectively. Apart from these, solar home systems account for only around 4% of the electricity consumed by households in both groups (4.81% vs. 3.85%). Alternative sources of fuel or light such as kerosene lamps and charger lights are also used when there is no access to electricity.

Table 3.6: Electricity access of HH members

Categories	Treatment	Control	Diff.	p-value
Access to electricity	95.60	93.60	2.00	0.16
Source of electricity (%)				
Minigrid/grid	95.19	96.15	-0.97	0.47
Solar home system	4.81	3.85	0.97	0.47
Time period attributed to electricity usage (months)	80.02929	71.41453	8.614759	0.1313
N	478	468		
Source of light/fuel used in the evenings if there is no access to electricity (%)				
Kerosene lamp	90.91	100.00	-9.09	0.08
Charger light	9.09	0.00	-9.09	0.08
N	22	32		

Source: BIDS Survey (2018).

3.4.3 Drinking Water Sources

This section demonstrates the principle sources of drinking water for treatment and control households (Table 3.7). The results show that the main source of drinking water is tube-wells without arsenic contamination for treatment and control groups (i.e. 86.20% vs. 85.80%) respectively. Arsenic contaminated tube wells are still a source of water for 4.80% of the treatment households and 3.00% of control households.

Table 3.7: Principle sources of drinking water (%)

Sources of Drinking Water	Treatment	Control	Diff.	p-value
Tube well (arsenic contaminated)	4.80	3.00	1.80	0.14
Tube well (no arsenic contamination)	86.20	85.80	0.40	0.86
Tube well (arsenic contamination not checked)	8.60	10.40	-1.80	0.33
Pump machines (by motorized tube well water)	0.40	0.80	-0.40	0.41
Total	500	500		

Source: BIDS Survey (2018).

3.4.4 Sanitation Facilities

Data on the types of latrine used by the sample households in the treatment and control groups have been presented in Table 3.8. Our findings reveal that the most common form of latrines used by households is the ring slab (water not sealed) by both treatment and control households (32.60% vs. 36.80%), followed by sanitary latrines with septic tank (23.80% vs. 21.60%), ring slab (water sealed) (23.40% vs. 20.40%) respectively with minor variations between the groups, although not significant.

Table 3.8: Types of latrine the households Use (%)

Types of Latrine	Treatment	Control	Diff.	p-value
Sanitary latrine with septic tank	23.80	21.60	2.20	0.41
Ring slab (water sealed)	23.40	20.40	3.00	0.25
Ring slab (water not sealed)	32.60	36.80	-4.20	0.16
Ordinary pucca	17.40	17.20	0.20	0.93
Kancha (without septic tank)	2.60	3.60	-1.00	0.36
Bush/open space/Other	0.20	0.40	-0.20	0.56
Total	500	500		

Source: BIDS Survey (2018).

3.5 Agricultural Loan

Our findings show that control households have a higher amount of outstanding agricultural loan (Tk. 33966.19) compared to treatment households (Tk. 24419.03), which is marginally significant (Table 3.9). The survey results indicate that the primary sources of agricultural loan for the households is the microfinance institutions (i.e. 40.78% vs 27.62%), commercial/agricultural banks (39.81% vs. 41.90%) and unofficial sources/mahajan (25.24% vs. 34.29%).

Table 3.9: Loan for Agricultural activities

	Treatment	**Control**	**Diff.**	**p-value**
Amount of outstanding agricultural loan (tk.)	24419.03	33966.19	-9547.16	0.09
Source of agricultural loan (%)				
Commercial/agricultural banks	39.81	41.90	-2.10	0.76
Microfinance institutions	40.78	27.62	13.16	0.05
Unofficial sources/Mahajan	25.24	34.29	-9.04	0.15
Other Sources (specify)	0.00	1.90	-1.90	0.16

Source: BIDS Survey (2018).

CHAPTER 4: VARIOUS ASPECTS OF IRRIGATION AND CROP PRODUCTION

In this chapter we provide information related to irrigation and its impact on agricultural production. We have furnished the information according to various harvesting seasons considering season-wise variations in irrigation use and production pattern.

4.1 Crop production related information

4.1.1 Plot Information

The survey findings suggest that farmers harvest in higher number of plots (on average 3) in Rabi and Kharif-2 seasons compared to Kharif-1 season (1.6 plots). The results show that farmers those are using solar irrigation (treatment) had harvested in significantly higher number of plots (3 vs 2.7 plots in Kharif-2 and 3.17 vs 2.8 plots in Rabi) and higher areas of land (1.35 vs 1.26 acre in Kharif-2 and 1.4 vs 1.3 acre in Rabi) compared to non-solar irrigation user group. Solar irrigation appears to facilitate farmers to harvest in more areas and plots in relatively longer seasons like Kharif-2 and Rabi contributing to higher yield by providing them with cheaper irrigation opportunities with reliability and accessibility of irrigation water. (Table 4.1)

Table 4.1: Number of Plots, Area and Yield

Panel A: Kharif-1 Season (mid-March to mid-July)

Category	Treatment	Control	Difference	p-value
Number of plots harvested	1.62	1.65	-0.03	0.76
Area (acre)	.71	.70	.01	0.8

Panel B: Kharif-2 Season (mid-July to mid-November)

Category	Treatment	Control	Difference	p-value
Number of plots harvested	3.00	2.69	0.31	0.00
Area (acre)	1.35	1.26	0.09	0.16

Panel C: Rabi Season (November to April)

Category	Treatment	Control	Difference	p-value
Number of plots harvested	3.17	2.80	0.36	0.00
Area (acre)	1.41	1.32	0.09	0.19

Source: BIDS Survey (2018).

4.1.2 Crop Production-related Expenditure

The survey results suggest that, throughout all three seasons, the cost of solar irrigation was lower than that of other methods of irrigation that the control group used, in particular diesel-based irrigation. These results strongly support the argument of cost reduction through the use of solar irrigation, especially considering the fact that solar irrigation users harvest in a higher number of plots and on a greater area of land (see Table 4.2). In addition, because of this trend of a larger use of land among solar irrigation users (treatment), their overall input cost (pesticide, fertilizer, draft animals, power tillers, seeds, and hired labor) was also higher than that of non-solar irrigation users. As a result, the net return from the crop (rice and non-rice) harvest for the farmers who use solar irrigation was higher in all the seasons (except Kharif-2, but insignificantly) than for non-solar irrigation users (Table 4.2). One possible explanation for this finding could be that the cost of solar irrigation is lower and SIP users get adequate irrigation water which resulted in higher net return. Though this is not a causal relationship, we shall investigate the issue using regression techniques in section 4.8.

Table 4.2: Costs and Returns of Crop Cultivation

Panel A: Kharif-1 Season (mid-March to mid-July)

Category	Treatment	Control	Difference	p-value
Irrigation cost (Tk per bigha)	1106.1	1250.89	-244.79	0.01
Total input cost (Tk per decimal on average)	192.67	204.61	11.94	0.60
Net return on rice (Tk per decimal on average)	138.47	140.76	-2.30	0.70
Net return on non-rice (Tk per decimal on average)	900.14	663.76	236.39	0.02

Panel B: Kharif-2 Season (mid-July to mid-November)

Irrigation cost (Tk per bigha)	1217.43	1410.56	-193.13	0.00
Total input cost (Tk per decimal on average)	177.13	160.11	17.02	0.004
Net return on rice (Tk per decimal on average)	145.96	146.87	-0.91	0.70
Net return on non-rice (Tk per decimal on average)	1675.21	1617.73	57.49	0.91

Panel C: Rabi Season (November to April)

Irrigation cost (Tk per bigha)	2472.91	4129.73	-1656.82	0.00
Total input cost (Tk per decimal on average)	244.47	233.44	11.02	0.14
Net return on rice (Tk per decimal on average)	147.09	149.17	-2.08	0.03
Net return on non-rice (Tk per decimal on average)	774.16	628.95	145.21	0.07

Note: -The cost of irrigation per bigha for control group was calculated from the farmers who subscribe irrigation (diesel-based) from a vendor. Those who own diesel pump and irrigate own land, their cost of irrigation was not considered.
-Data from decimal to bigha can be converted by considering 1 bigha= 33 decimals.

Source: BIDS Survey (2018).

4.1.3 Irrigation Specific Information

Some of the characteristics of solar irrigation are discernible in Table 4.3. The survey findings suggest that, in all the seasons, the percentage of area covered with irrigation was slightly higher for the control groups than for the solar irrigation users (85.67% vs 92.05% in Kharif-1, 83.05% vs 86.02% in Kharif-2, and 95.89% vs 96.89% in Rabi). One interesting observation is that solar irrigation facilitates the coverage of a comparatively much longer distance between source and plot in every season (96.74 vs 74.51 in Kharif-1, 131.70 vs 82.83 in Kharif-2, and 138.03 vs 75.34 in Rabi). Solar irrigation projects provide irrigation facilities for a longer period in terms of the number of days in all the seasons, which might have contributed to the higher yield. On the other hand, solar irrigation appears to provide irrigation for relatively fewer hours in a day than diesel pumps, which may be due to its lower wastage of water (as it uses submersible pipes) than other modes of irrigation. A larger proportion of farmers using solar irrigation reported that they received adequate water than those using non-solar modes of irrigation, which is a testament to the increased efficiency in irrigation that the use of solar irrigation offers (Table 4.3).

Table 4.3: Availability, Utilization, Modes, and Intensity of Solar Irrigation

Panel A: Kharif-1 Season (mid-March to mid-July)

Category	**Treatment**	**Control**	**Difference**	**p-value**
Area with irrigation available (%)				
Area with irrigation availed (%)	85.67	92.05	-6.38	0.01
Distance between irrigation plant and plot (ft)	96.74	74.51	22.23	0.06
Number of days irrigated (days)	4.91	4.23	0.68	0.02
Number of hours irrigated per day (hours)	1.82	1.73	0.09	0.45
Received adequate water (yes; %)	41.91	45.17	-3.26	0.25
Panel B: Kharif-2 Season (mid-July to mid-November)				
Area with irrigation availed (%)	83.05	86.02	-2.97	0.03
Distance between irrigation plant and plot (ft)	131.70	82.83	48.87	0.00
Number of days irrigated (days)	8.65	7.49	1.17	0.00
Number of hours irrigated per day (hours)	1.74	1.90	-0.16	0.01
Received adequate water (yes; %)	76.13	71.90	4.24	0.01
Panel C: Rabi Season (November to April)				
Area with irrigation availed (%)	95.89	96.89	-1.00	0.15
Distance between irrigation plant and plot (ft)	138.03	75.34	62.69	0.00
Number of days irrigated (days)	32.91	27.89	5.02	0.00
Number of hours irrigated per day (hours)	1.94	2.00	-0.06	0.62
Received adequate water (yes; %)	87.61	77.89	9.72	0.00

Source: BIDS Survey (2018).

4.1.4 Comparative Analysis between Diesel pump Owners vs. Diesel Pump Non-Owner

We have already seen that the non-solar irrigation user group (control group) depends mainly on diesel pumps for irrigation (see Table 4.4). They can be divided into two groups: diesel pump owners and diesel pump non-owners. And, the cost of irrigation they concur also varies both in amount and type of cost according to the category they fall in. The diesel pump owners reported that the use of diesel pumps for irrigation was significantly higher in the Kharif-1 season compared to the other two seasons (82.91% in Kharif-1 compared to 65.86% in Kharif-2 and 47.23% in Rabi). Kharif-1 season is comparatively a dry season, so the higher need of irrigation bears from this fact. Kharif-2 season has plenty of rainfall, so the need for irrigation is reduced and Rabi rice is mainly cultivated in low lands already inundated with rainwater from the rainy season resulting in even further reduction in terms of need for irrigation. The age of the pumps does not vary significantly. The pump owners also reported to need slightly less amount of diesel to irrigate per bigha of land in the Kharif-1 season compared to the other two (on either side of 3 liters per bigha). The cost of diesel duly followed this trend. The repair and maintenance costs of pumps and other machineries were observed to be much higher in the Rabi season (983.83 in Rabi vs 453.09 in Kharif-1 and 617.11 in Kharif-2). The number of casualties or hazards was not found to vary significantly based on the season. On the other hand, those who do not own pumps but pay for the diesel reported to pay for less portion of the diesel used in irrigation in Kharif-2 and Rabi seasons compared to the Kharif-1 season (0.44% in Kharif-2 and 40% in Rabi vs 63.95% in Kharif-1). Perhaps, the terms of contract with pump owners vary based on the season. The used amount of diesel to irrigate per bigha of land and average cost of diesel followed through the trend of that of pump owners, the lowest in Kharif-1 and then gradually higher in Kharif-2 and the highest in Rabi. They also needed to buy diesel more number of days according to the usage pattern of diesel. But, the time spent to buy diesel was almost same in every season (around 40 min/day). Excluding cost of diesel the pump no-owners also had to pay a lump-sum amount to the pump owners to use the diesel pumps and had to incur other costs related to irrigation. These figures varied from season to season. And, then there is a subgroup of diesel pump non-owners who did not pay for the diesel. They only paid a lump-sum amount to the pump owners to use the pumps for irrigation. This payment included all costs and prices from the pump-owners side. The amount of payment was the lowest in Kharif-1 season, slightly higher in Kharif-2 season and the highest in Rabi season (1111.11 in Kharif-1, 1401.60 in Kharif-2 and 4095.41 in Rabi). May be the lower area of land cultivated in the Kharif-1 season contributed to the lower value in Kharif-1 season and the higher volume of rainfall in the Kharif-2 season mitigated the need of irrigation in general. They also incurred some other irrigation related costs in every season. (Table 4.4)

Table 4.3: Comparative Analysis between Diesel pump Owners vs. Diesel Pump Non-Owners (Season wise)

Category	Kharif-1 season	Kharif-2 season	Rabi season
For respondents with their own diesel pumps			
Used diesel pump for irrigation (%)	82.91	65.86	47.23
Age of the pump (years) (average)	7.85	8.19	8.41
Average amount of diesel required to irrigate per bigha of your own land (liter for all season)	2.69	3.66	3.51
Average cost of diesel (taka)	181.02	247.48	236.59
Average cost of diesel pump repair, maintenance and other machineries related expenditure (taka)	453.09	617.11	983.83
Faced any casualties/hazards due to diesel irrigation pumps (%)	1.03	0.00	0.43
For respondents who don’t have their own diesel pumps but pay for diesel			

Category	Kharif-1 season	Kharif-2 season	Rabi season
Paid for diesel used in irrigation (%)	63.95	0.44	40.00
Avg. amount of diesel required to irrigate per bigha of land (liter for all season)	3.53	5.51	20.67
Avg. cost of diesel (taka)	232.11	378.73	1437.35
Frequency of travel (days) to purchase diesel per season	3.40	5.48	12.29
Avg. amount time spent for buying diesel per day (min./day)	43.62	38.24	42.56
Excluding diesel payment, avg. amount paid to the pump owner for irrigation (taka)	153.38	242.65	106.12
Other costs related to irrigation that was incurred (excluding earlier payments) (taka)	41.27	42.59	142.21
For respondents who don't have their own diesel pumps but don't pay for diesel			
Avg. amount paid to the pump owner for irrigation (taka)	1111.11	1401.60	4095.41
Other costs related to irrigation that was incurred (excluding earlier payments) (taka)	27.78	8.96	34.32

Source: BIDS Survey (2018).

4.2 Solar Irrigation related Issues

The survey findings provided us with the opportunity to understand the solar irrigation adoption-related issues for both the treatment and the control households. The survey modules further provides information on various modes of PO training, distance information, costs incurred and most importantly, the reasons behind for not adopting to solar irrigation among the control households.

4.2.1 Households with Solar Irrigation

The solar-powered pump user farmers have used solar irrigation for an average of 2.82 years. Among them, around 21.40% had received training from PO on time management for irrigation water use. Around 47.54% of the respondents believe they use solar irrigation because diesel irrigation pumps are too expensive, whilst around 16.94% adopted solar irrigation under the influence of friends/relatives and neighbors. Only 5.75% believed solar irrigation increases agricultural production, and 7.60% reported that they were not satisfied with the current service. (Table 4.5)

Table 4.4: **For HHs with solar irrigation**

Category	Treatment HHs
Average no. of years solar irrigation is used (years)	2.82
Receive training from PO for the following (%)	
Solar irrigation machine usage	2.20
Crop management*	9.40
Time management for irrigation water use	21.40
Fertilizer/seed/insecticide use	16.40
Reasons for using Solar Irrigation (%)	
Diesel irrigation pumps are too expensive	47.54
Not satisfied with current service	7.60
Solar irrigation increases agricultural production	5.75
Friends/ relatives and neighbors have taken it	16.94
Solar irrigation is environmentally friendly	12.22
Others	9.96

Source: BIDS Survey (2018).

4.3 Comparative Analysis of Knowledge/Information

One of the most popular sources of knowledge about solar irrigation before adoption is the experiences of friends and neighbors for both solar irrigation users (treatment group) and non-users (control group) (i.e. 80.80% vs. 84.40%) respectively. For farmers who use solar irrigation, around 70.40% of the households gather information from the pump owner or sponsor. Both solar irrigation user and non-user groups attained some information from village leaders (24.20% vs. 17.20%) and brochures and leaflets (26.00% vs. 11.00%) respectively. The least favored sources are found through village meetings and public announcements. (Table 4.6)

Table 4.5: Comparative Analysis of Knowledge/Information

Category	Treatment	Control
Sources of knowledge about Solar irrigation system before adoption		
From village leader	24.20	17.20
From pump owner/sponsor	70.40	27.20
From village meetings	1.80	1.20
Brochures/leaflets/posters	26.00	11.00
Friends/Neighbors’	80.80	84.40
From public announcement in the village	1.80	0.20
Others	27.60	27.00

Source: BIDS Survey (2018). *note: Multiple responses are taken into account

4.4 Time Use of the households

The average time use of household members who are engaged in agricultural activities has been recorded in minutes by the enumerators. The findings suggest that on average, the treatment households spend around 315.79 minutes per day in own income-generating activities or business compared to around 326.55 minutes per day by that of the control households. This information has been followed by resting, taking daytime nap, etc. (74.99 min. vs. 71.01 min.), socializing, visiting neighbors, friends, relatives, entertaining guests (52.50 min. vs. 49.77 min.), watching television (51.12 min. vs. 46.91 min.),religious activities (45.56 min. vs. 44.29 min.), washing clothes and other cleaning activities (30.12 min. vs. 29.85 min.), household work or chores (15.34 min. vs. 12.14 min.), using mobile phones for conversation only (10.66 min. vs. 10.23 min.) and wage or salaried work (10.49 min. vs. 6.92 min.) for both treatment and control households respectively (see Appendix: Table A1).

4.5 Impacts on Economic Outcomes

We looked at the impacts on overall crop production, irrigation-related expenditure and net return. Our findings suggest that the average annual value of overall crop production is higher for the solar irrigation users compared to that of the farmers not using solar irrigation (i.e. Tk. 346374.2 vs. Tk. 177090.5), albeit not significant. The average expenditure related to irrigation is also found to be significantly higher for the solar irrigation user (treatment) group than that of the non-user (control) group (Tk. 59547.18 vs. Tk. 52597.58) respectively. This result in an overall increase in net return for the farmers using solar irrigation compared to those who do not use solar irrigation (i.e. Tk. 286827.1 vs. Tk. 124492.9) respectively as well, despite being insignificant. (Table 4.7)

Table 4.6: **Economic impacts**

Outcome Variable (per acre)	**SI HHs**	**Non- SI HHs**	**Diff.**	**p-value**
Annual value of overall crop production (taka) (avg.)	343315.9	146922.6	196393.4	0.1540
Irrigation related expenditure (taka) (avg.)	46981.83	43260.67	3721.167	0.1745
Net Return	296334.1	103661.9	192672.2	0.1576

Source: BIDS Survey (2018). *note: values are aggregated across 3 seasons

4.6 Reduction of Carbon Emissions

Based on diesel use per acre of land, we have estimated carbon emission by different types of pumps based on their longevity. Our estimation results suggest that with the increase in age of the diesel pumps, their carbon emission also increases. On average the diesel pumps emit 7.5

Kg Carbon Dioxide among the three seasons amassing 22.3484 Kg per acre over the course of a year (Table 4.8). The variation in carbon emission across seasons may be due to reporting bias.

Table 4.7: Carbon Dioxide (CO_2) from Diesel Pumps

Category	**Estimated Carbon emitted by pumps (Kg)**
Carbon Emission per acre (Kharif-1)	**Control group**
Pump age 1-5 years	5.988
Pump age 6-10 years	8.5492
Pump age 11-15 years	9.2728
Total average (A)	**7.9367**
Carbon Emission per acre (Amon)	
Pump age 1-5 years	6.6732
Pump age 6-10 years	7.37
Pump age 11-15 years	8.2276
Total average (B)	**7.426**
Carbon Emission per acre (Rabi)	
Pump age 1-5 years	5.226
Pump age 6-10 years	7.2092
Pump age 11-15 years	7.6648
Pump age 16-25 years and above	7.8524
Total average (C)	**6.9881**
Overall (A+B+C)	**22.3484**

Source: Authors' Calculations.

Note: This calculation has been based upon the conversion estimates from U.S. EPA Centre for Corporate Climate Leadership, 2016 report i.e. 1 liter diesel burnt = 2.68 Kg CO_2

4.7 Opinions and attitude towards solar irrigation

We also sought perception and opinion of both the solar irrigation user (treatment) and non-user (control) groups about various aspects of solar irrigation and documented their responses (see Appendix: Table A2). The farmers who have used solar irrigation were asked whether they found solar irrigation to be less expensive relative to other irrigation method or not. Almost over 90% of them agreed that solar irrigation was less expensive, reliable than other methods of irrigation, environmentally friendly, and saves time and labor. In response to the same question, control group also agreed overwhelm on these positive benefits of solar irrigation. Regarding some bad/negative aspects of diesel-based irrigation, such as bad smell during the use of diesel engine, excessive noise and smoke creation etc., a majority of both groups agreed on these negative aspects.

4.8 Impact of solar irrigation on adequacy of water and costs of irrigation

Our econometric model specification is as follows:

$$Y_{ijs} = \alpha X_{ij} + \beta V_j + \gamma I_{ijs} + \delta P_{ijs} + \lambda O_{ijs} + \varepsilon_{ijs}$$

Here, Y is the outcome, X is household level controls, V is village level controls, I is the dummy for mode of irrigation (solar), P is total plot size or plot fertility, and O is other inputs. Then we run season-specific regression for above equation for Kharif-1, Kharif-2 or Rabi season. More specifically, Y_{ij} represents seasonal (i.e. Kharif-1, Kharif-2 and Rabi) adequacy of water in terms of hours of operation or input costs of total production for household i in village j; I indicates a dummy variable i.e. if the household use solar irrigation in different seasons = 1, 0 otherwise; X_{ij} denotes household-level characteristics (e.g. age, marital status, formal education, house ownership, land ownership, access to electricity, safe drinking water and sanitation); V_j indicates village-level characteristics which includes village population, households in village, total number of solar pump user, total number of diesel pump user, landless (below 0.5 acre), marginal land holder (0.5-1 acre), small land holder (1-2.5 acre), medium land holder (2.5-7.5 acre) etc.; α_1 represents the coefficients for seasonal solar irrigation use, household-level and village-level characteristics respectively and ε_{ij} captures the error term.

Table A3 in appendix represents the impacts of adopting solar irrigation on meeting the adequacy of water required for the purpose of irrigation. We used OLS regressions across seasons to see whether solar irrigation provides adequate amount of irrigation water compared to diesel-based irrigation. We measured adequacy of water used for irrigation in terms of three variables: hours per day irrigation water received, number of days irrigation is used in a season and interaction between these two to have number of hours of irrigation is provided in a season. The regression results are provided for all three seasons. The results imply that solar irrigation provides irrigation water for higher number of days but less number in hours indicating its adequacy and reliability. The reason is that diesel pumps might have provided water for a smaller number of days and greater number of hours just to save diesel cost, which may not be efficient.

In Table A4 in appendix we assessed the impacts of adoption of solar irrigation on the cost of production in Kharif-2 and Rabi seasons across plots. Except for plot 5 in Rabi season, the impact of solar irrigation is negative though insignificant. For Kharif-2 season, the impact is also insignificant. The results provide an indication that solar-powered irrigation reduces cost of production marginally though reduction of cost is not that significant.

CHAPTER 5: SUMMARY AND CONCLUSIONS

The purpose of the impact assessment study is to estimate the socio-economic benefits of solar irrigation compared to the non-solar based irrigation used in selected locations. For this purpose, a total of 1000 households have been systematically randomly selected and surveyed. Out of the total sample size, 500 households were solar irrigation adopted farmers (i.e. treatment) and the remaining 500 households were non-adopter (i.e. control) households.

The results show that farmers those are using solar irrigation (treatment) had harvested in significantly higher number of plots (3 vs 2.7 plots in Kharif-2 and 3.17 vs 2.8 plots in Rabi) and higher areas of land (1.35 vs 1.26 acre in Kharif-2 and 1.4 vs 1.3 acre in Rabi) compared to non-solar irrigation user group. Reliability, accessibility and affordability of solar irrigation may have prompted farmers to harvest in more areas and plots in relatively longer seasons like Kharif-2 and Rabi.

It has been also observed that throughout all three seasons the cost of irrigation was lower for the farmers using solar irrigation (treatment) compared to those using other methods of irrigation (control) (1106.1 vs 1138.89 in Kharif-1, 1217.43 vs 1410.56 in Kharif-2 and 2946.91 vs 4129.73 in Rabi). These results strongly support the argument of reduction of cost through use of solar irrigation. We also looked at the impacts of solar irrigation on adequacy of water and cost of production. We found that solar irrigation offers greater efficiency, reliability and access to meet the adequacy of irrigation water throughout all three seasons. It also appears to reduce the cost of production marginally albeit the reduction being not that significant.

Solar irrigation saves carbon emission. Based on diesel use per acre of land, we have estimated carbon emission by different types of pumps based on their longevity. Our estimation results suggest that with the increase in age of the diesel pumps, their carbon emission also increases. On average the diesel pumps emit 7.5 Kg Carbon Dioxide among the three seasons amassing 22.3484 Kg per acre over the course of a year.

Finally, solar irrigation provides opportunity to irrigate a higher amount of land due to reliability, affordability and accessibility, and therefore it also contributes to higher amount of return from harvesting. Moreover, it saves carbon emission and therefore contributes to reducing air pollution. More awareness building efforts are needed in this regard so that more farmers can get benefit out of it. Also it is important to make solar irrigation more affordable to customers as well as investors. Apart from the donor financing, IDCOL might think of issuing green bonds to finance SIPs in a sustainable manner. Dynamic adjustment of prices of solar irrigation related equipment is needed. We also suggest that apart from tangible benefits that we have discussed in this chapter, it is also important to assess the environmental impact of depletion of deep ground water due to the use of solar irrigation pumps. Excess electricity generated from SIPs during off seasons and off-days may be used in a more effective way by linking them with national grid. For this purpose, proper policies and incentives would be required from the part of the government.

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Appendix

Table A1: Time Use of household members engaged in agricultural activities (min/day)

Types of activities	Treatment	Control	Diff.	p-value
Wage/salaried work	10.49	6.92	3.57	0.32
Own income-generating activities/business	315.79	326.55	-10.76	0.16
Household work/chores	15.34	12.14	3.20	0.08
Cooking/preparing meals/boiling water/cleaning stoves	1.56	0.37	1.19	0.08
Eating/serving meals (including carrying food to husband's workplace/field)	2.75	3.28	-0.53	0.46
Washing clothes and other cleaning activities	30.12	29.85	0.27	0.83
Collecting fuel	2.40	3.67	-1.27	0.08
Collecting water	0.37	0.57	-0.20	0.28
Reading and studying	1.23	2.05	-0.82	0.42
Using computers	0.21	0.17	0.03	0.72
Using mobile phones for conversation only	10.66	10.23	0.43	0.41
Using mobile phones for accessing information and knowledge	2.94	3.36	-0.42	0.56
Taking care of children (incl. bathing, feeding, dressing etc.)	9.74	9.48	0.26	0.84
Helping with children's study/homework	4.42	4.91	-0.49	0.58
Watching television	51.12	46.91	4.21	0.08
Listening to radio	0.42	0.18	0.24	0.34
Socializing, visiting neighbors, friends, relatives, entertaining guests	52.50	49.77	2.73	0.25
Attending community activities, meetings	5.52	4.06	1.46	0.11
Resting, taking daytime nap, etc.	74.99	71.01	3.98	0.14
Religious activities	45.56	44.29	1.27	0.67

Source: BIDS Survey (2018).

Table A2: Opinions and attitude towards solar irrigation

List of Statements	Treatment	Control	Diff.	p-value
Solar irrigation is less expensive relative to other irrigation methods				
Strongly Agree	71.20	31.80	39.40	0.00
Agree	24.60	49.00	-24.40	0.00
Neutral	0.80	16.20	-15.40	0.00
Disagree	3.40	3.00	0.40	0.72
Strongly Disagree	0.00	0.00	0.00	
Solar irrigation is reliable than other irrigation methods				
Strongly Agree	56.40	29.80	26.60	0.00
Agree	36.00	32.20	3.80	0.21
Neutral	3.20	33.40	-30.20	0.00
Disagree	4.00	4.60	-0.60	0.64
Strongly Disagree	0.40	0.00	0.40	0.16
Solar irrigation system is reliable				
Strongly Agree	53.00	29.20	23.80	0.00
Agree	38.60	28.60	10.00	0.00
Neutral	5.20	39.40	-34.20	0.00
Disagree	3.00	2.80	0.20	0.85
Strongly Disagree	0.20	0.00	0.20	0.32
Solar irrigation is environmentally friendly and reduces pollution				
Strongly Agree	75.40	49.20	26.20	0.00
Agree	24.40	36.80	-12.40	0.00
Neutral	0.20	13.40	-13.20	0.00
Disagree	0.00	0.60	-0.60	0.08
Strongly Disagree	0.00	0.00	0.00	
Solar irrigation saves time				
Strongly Agree	71.80	43.40	28.40	0.00
Agree	26.00	41.80	-15.80	0.00
Neutral	2.20	14.20	-12.00	0.00
Disagree	0.00	0.60	-0.60	0.08
Strongly Disagree	0.00	0.00	0.00	
Solar irrigation saves labor				
Strongly Agree	71.60	43.80	27.80	0.00
Agree	26.80	42.80	-16.00	0.00
Neutral	0.60	12.60	-12.00	0.00
Disagree	1.00	0.60	0.40	0.48
Strongly Disagree	0.00	0.20	-0.20	0.32

List of Statements	Treatment	Control	Diff.	p-value
During diesel irrigation use, there is a bad smell				
Strongly Agree	55.80	49.00	6.80	0.03
Agree	39.40	45.60	-6.20	0.05
Neutral	0.60	0.80	-0.20	0.70
Disagree	4.20	4.60	-0.40	0.76
Strongly Disagree	0.00	0.00	0.00	
There is smoke when operating diesel run irrigation machines				
Strongly Agree	69.00	60.40	8.60	0.00
Agree	30.20	39.20	-9.00	0.00
Neutral	0.60	0.40	0.20	0.65
Disagree	0.20	0.00	0.20	0.32
Strongly Disagree	0.00	0.00	0.00	
There is a lot of noise while operating diesel based irrigation machines				
Strongly Agree	74.40	69.80	4.60	0.10
Agree	25.00	29.60	-4.60	0.10
Neutral	0.40	0.60	-0.20	0.65
Disagree	0.20	0.00	0.20	0.32
Strongly Disagree	0.00	0.00	0.00	
The diesel used in irrigation machines/pumps contains impurities				
Strongly Agree	24.40	18.80	5.60	0.03
Agree	53.00	51.00	2.00	0.53
Neutral	11.40	17.00	-5.60	0.01
Disagree	11.20	13.20	-2.00	0.33
Strongly Disagree	0.00	0.00	0.00	

Source: BIDS Survey (2018).

Table A3: Impact of SIP on adequacy of irrigation water

VARIABLES	Log (No of days irrigation was used per season)	Log (No of hours irrigation was used per day)	Log (No of hours irrigation was used per season)	Log (No of days irrigation was used per season)	Log (No of hours irrigation was used per day)	Log (No of hours irrigation was used per season)	Log (No of days irrigation was used per season)	Log (No of hours irrigation was used per day)	Log (No of hours irrigation was used per season)
	Kharif-1	Kharif-1	Kharif-1	Kharif-2	Kharif-2	Kharif-2	Rabi	Rabi	Rabi
Solar irrigation	0.323***	-0.240**	0.082	0.259***	-0.146***	0.114	0.324***	-0.118**	0.205***
	(0.080)	(0.097)	(0.123)	(0.057)	(0.048)	(0.072)	(0.042)	(0.046)	(0.061)
Plot fertility	-0.037	-0.204**	-0.234**	-0.231***	-0.121***	-0.351***	-0.173***	-0.080**	-0.251***
	(0.073)	(0.090)	(0.112)	(0.052)	(0.042)	(0.061)	(0.038)	(0.039)	(0.053)
Distance between source of irrigation and plot (ft)	-0.000	-0.001*	-0.001	-0.000	-0.001***	-0.001***	0.000	-0.001***	-0.001***
	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Plot type	-0.135**			0.038			0.045		
	(0.058)			(0.049)			(0.038)		
Age	0.001	0.001	0.001	0.001	-0.000	0.001	0.005***	-0.002	0.003
	(0.003)	(0.004)	(0.005)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Marital status	0.020	-0.151	-0.099	-0.107	-0.034	-0.143	-0.130	-0.034	-0.166
	(0.106)	(0.190)	(0.260)	(0.149)	(0.085)	(0.174)	(0.089)	(0.105)	(0.107)
Formal education	-0.010	0.052	0.023	-0.112**	0.099**	-0.011	-0.027	0.032	0.008
	(0.072)	(0.091)	(0.111)	(0.053)	(0.046)	(0.064)	(0.041)	(0.044)	(0.058)
House ownership	-0.667***	-0.643***	-1.409***	-0.086	-0.253	-0.352*	-0.008	-0.106	-0.129
	(0.101)	(0.108)	(0.147)	(0.246)	(0.194)	(0.194)	(0.288)	(0.226)	(0.425)
Land ownership	0.000	0.001***	0.001**	0.000	0.001***	0.001***	-0.000	0.001***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Access to safe drinking water	-1.507***	0.409***	-0.960***	-0.052	-0.458	-0.519***	0.184	-0.216	-0.043
	(0.096)	(0.095)	(0.123)	(0.345)	(0.393)	(0.149)	(0.207)	(0.283)	(0.340)
Access to sanitation	-0.037	0.196	0.139	-0.104	0.162	0.054	-0.187***	0.086	-0.100
	(0.294)	(0.243)	(0.432)	(0.154)	(0.118)	(0.207)	(0.060)	(0.113)	(0.117)
Total household in village	-0.001**	0.002***	0.001	-0.001***	0.001***	0.000	-0.001***	0.001***	-0.000
	(0.000)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Total people in village	-0.000	-0.000	-0.000	-0.000	-0.000**	-0.000***	0.000	-0.000**	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Total diesel pump user in	0.000	-0.001*	-0.000	0.001***	-0.001***	0.001*	0.000	-0.000	0.000

village									
	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Landless	0.003**	-0.005***	-0.002	0.003***	-0.002***	0.000	0.001	-0.002***	-0.001*
	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)
Landowner (marginal)	0.117*	-0.070	0.063	0.352***	-0.192***	0.154**	0.115**	-0.106**	-0.002
	(0.070)	(0.094)	(0.115)	(0.054)	(0.047)	(0.068)	(0.045)	(0.041)	(0.059)
Landowner (small)	-0.017	-0.014	0.010	0.154**	0.137**	0.283***	-0.025	0.088	0.052
	(0.116)	(0.140)	(0.176)	(0.067)	(0.061)	(0.074)	(0.056)	(0.055)	(0.074)
Landowner (medium)	-0.022	0.022	-0.011	-0.064	-0.043	-0.102*	0.217***	-0.047	0.180***
	(0.081)	(0.094)	(0.130)	(0.051)	(0.045)	(0.057)	(0.038)	(0.037)	(0.049)
Constant	3.461***	0.865*	3.875***	0.387	1.349***	1.877***	2.406***	1.013**	3.586***
	(0.509)	(0.476)	(0.682)	(0.504)	(0.446)	(0.413)	(0.386)	(0.397)	(0.554)
Observations	328	328	328	821	821	821	958	958	958
R-squared	0.166	0.196	0.104	0.366	0.264	0.196	0.277	0.206	0.168

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

Table A4: Impact of SIP on cost of production

VARIABLES	Log (per Decimal Cost of Production)	Log (per Decimal Cost of Production)	Log (per Decimal Cost of Production)	Log (per Decimal Cost of Production)	Log (per Decimal Cost of Production)	Log (per Decimal Cost of Production)	Log (per Decimal Cost of Production)	Log (per Decimal Cost of Production)
	Plot-1 Kharif-2	Plot-2 Kharif-2	Plot-3 Kharif-2	Plot-1 Rabi	Plot-2 Rabi	Plot-3 Rabi	Plot-4 Rabi	Plot-5 Rabi
Solar Irrigation	0.018	0.018	-0.004	-0.039	-0.031	-0.053	-0.061	-0.183**
	(0.025)	(0.025)	(0.032)	(0.032)	(0.034)	(0.035)	(0.051)	(0.071)
Plot fertility	-0.062**	-0.043*	-0.020	-0.023	-0.038	-0.077**	-0.158***	-0.285***
	(0.024)	(0.025)	(0.029)	(0.028)	(0.029)	(0.031)	(0.054)	(0.095)
Distance between source of irrigation and plot (ft)	0.000	0.000	-0.000	0.000**	0.000*	-0.000	-0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

Age	0.001	0.001	-0.001	-0.001	-0.001	-0.000	0.001	0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.003)
Marital status	-0.133	-0.068	-0.057	0.073	0.023	0.084	0.127*	-0.175
	(0.096)	(0.048)	(0.069)	(0.079)	(0.055)	(0.088)	(0.069)	(0.180)
Formal education	0.066**	0.060**	0.059**	0.072**	0.028	0.004	0.035	-0.033
	(0.028)	(0.024)	(0.028)	(0.033)	(0.029)	(0.032)	(0.055)	(0.094)
House ownership	0.091	0.176	0.051	0.081	0.116	-0.118	-0.509***	
	(0.066)	(0.110)	(0.065)	(0.183)	(0.167)	(0.096)	(0.155)	
Land ownership	0.000	-0.000	0.000	-0.000**	-0.000***	-0.000***	-0.000**	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Access to safe drinking water	0.212	0.149	0.096*	-0.099	0.012	-0.062	-0.143	-0.287**
	(0.129)	(0.103)	(0.052)	(0.280)	(0.075)	(0.086)	(0.095)	(0.123)
Access to sanitation	-0.164*	-0.227*	-0.140**	-0.126*	-0.098	-0.086*	0.188	0.267
	(0.088)	(0.127)	(0.068)	(0.070)	(0.072)	(0.049)	(0.141)	(0.371)
Total household in village	0.000	0.000	0.000	0.000*	0.001***	0.000	0.000	0.001
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)
Total people in village	-0.000	-0.000*	-0.000	-0.000*	-0.000***	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Total diesel pump user in village	0.000	0.000	0.000	0.000	0.000***	-0.000**	-0.001**	-0.001
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Landless	0.001**	0.000	0.001*	0.000	-0.000	0.001	0.001	0.001
	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)
Landowner (marginal)	-0.026	0.010	-0.047	0.104***	0.079***	0.116***	0.018	-0.134
	(0.025)	(0.029)	(0.034)	(0.030)	(0.030)	(0.035)	(0.058)	(0.128)
Landowner (small)	0.048	-0.027	0.000	0.118***	0.049	-0.032	-0.042	0.103
	(0.036)	(0.030)	(0.036)	(0.043)	(0.044)	(0.043)	(0.078)	(0.147)
Landowner (medium)	0.012	0.040*	0.047	-0.107***	-0.069**	-0.038	-0.002	-0.072
	(0.026)	(0.022)	(0.029)	(0.032)	(0.031)	(0.039)	(0.058)	(0.111)
Constant	4.843***	4.858***	5.133***	4.894***	5.004***	5.330***	5.737***	5.869***
	(0.207)	(0.165)	(0.169)	(0.309)	(0.198)	(0.166)	(0.216)	(0.578)
Observations	803	670	418	912	784	508	275	109
R-squared	0.105	0.080	0.083	0.162	0.141	0.153	0.110	0.251

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

Final Report-PART III

Impact Assessment of Improved Cook Stove (ICS) Program of IDCOL

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EXECUTIVE SUMMARY

The objective of this study is to assess the socio-economic benefits of Improved Cook Stove (ICS) program of IDCOL. For this purpose, a total of 2000 households have been systematically randomly selected and surveyed. Out of the total sample size; 1000 households were ICS adopted households (i.e. treatment) and the remaining 1000 households were non-adopter (i.e. control) households. Several descriptive, statistical, and econometric methods have been used to process various sets of data and to examine the study objectives with special focus on understanding the socio-economic benefits of ICS on adopted (treatment) households compared to the non-adopted (control) households. The methods include analyses using simple t-statistics with ICS user and non-user in the same village and non-user in control villages; ordinary least square (OLS) and instrumental variable (IV) regression models to understand the socio-economic (e.g. fuel consumption, income, health etc.) impacts of ICS on household welfare.

The results depict that the total time for cooking meal is significantly (i.e. 156.24 minutes) lower for ICS (treatment) households compared to non-ICS (control) households (i.e. 174.71 minutes) exhibiting about 20 minutes **time savings** of the ICS adopters. The findings further reveal that around 9.00 minutes per week are required for preparing the stove before using and cleaning the stove after cooking which is significantly higher than that of the treatment households which needs around 7.59 minutes. The results indicate that ICS decreases time spent on fuel collection/purchase significantly and saves time.

On average, the respondents (i.e. ICS and non-ICS adopters) reportedly are found to use firewood/twigs as their primary fuel for cooking and parboiling purposes. The lasting of the fuel in terms of number of days exhibits an interesting pattern in terms of **fuel efficiency**. On average, fuel lasts around 69.90 days for the ICS (treatment) households than that of around 49.31 days lasting among the non-ICS (control) households with the difference being statistically significant. This might also indicate the two groups who do not buy the same amount of fuels. The total amount of costs incurred for acquiring fuels further revealed the **cost efficiency** pattern of the treatment (ICS) households. The survey findings show that the treatment group incurred around Tk. 389.31 which is significantly lower than the control group that stands at Tk. 463.88. ICS adopters are less exposed to CO emissions due to less smoke generation (0.70 vs. 0.72; based on PM2.5 / PM10 ratio).

To assess the impact of ICS adoption on various aspects, we run several regressions. The results suggest that ICS adoption reduces cooking time about 16 minutes a day and also fuel collection time by 15 minutes a month. Though saved time due to ICS use appears to be very negligible, this is statistically significant. Regression results also show that ICS user women's time use has

significantly increased, which is expected. Therefore, it may be concluded that ICS adoption can save time compared to adoption of traditional stove users, which they can utilize for other activities e.g. taking care of children, helping in children's study/homework, watching television, socializing and visiting neighbors, friends, relatives, entertaining guests, taking rest including wage/salaried work and IGAs.

In sum, though ICS adoption brought some positive benefits to user households, still a large section of households use both traditional and ICS simultaneously. Use of both types of stoves affected the positive benefits of ICS. Some negative aspects of ICS were also reported by the respondents which need to be addressed. Further improvement of ICS addressing households concern is expected to generate higher benefits of ICS. More awareness building programs are also needed to popularize ICS in Bangladesh.

CHAPTER 1: INTRODUCTION

1.1 ICS Program of IDCOL in Bangladesh

Cooking in rural Bangladesh is done predominately (by 90% of the household) in traditional stoves using biomass fuel such as wood, leaves, crop residues, jute sticks and animal dung. The combustion of these fuel in traditional stove not only is inefficient (5-15% fuel efficiency) but also produces smoke that causes indoor air pollution (IAP) and is particularly harmful to women and children (Hossain, 2003). According to World Health Organization (WHO), more than 100,000 people die every year in Bangladesh due to various diseases caused by IAP, which is also responsible for degradation of the natural environment and deforestation. IAP resulting from the smoke is linked with many diseases such as acute and chronic respiratory conditions, lung cancer, heart disease, stroke, and cataract. Since the transition to modern cooking fuels such as natural gas, liquefied petroleum gas (LPG) and electricity to some extent will take a long time to be accessible and affordable to majority of the rural population; transitory clean cooking options such as ICS could be a viable option. IDCOL's ICS Program was initiated in 2013 with the objective of controlling IAP and deforestation and aimed at installing 1 million stoves by December 2018. This has further established a strong base to achieve 100 percent coverage of improved stoves by 2030 in line with Bangladesh's Country Action Plan for Clean Cook stoves.

The overall objectives of IDCOL's ICS program are to reduce GHG emissions, solid fuel use for cooking and the impact of Indoor Air Pollution (IAP) - which substantially affects women and children - by creating a sustainable market-based approach towards adoption of higher efficiency cook-stoves in the country. The program has achieved its initial target of installing 1 million ICS by January, 2017, almost two years ahead of the project completion period. IDCOL's R&D initiatives upgraded the stoves under the program from Tier 1(>=15%) to Tier 3 (>=35%) level of thermal efficiency. Now, with increases in thermal efficiency, the stoves burn lesser amount of fuel and therefore, GHG Emission and IAP decrease significantly. So far 1.62 million ICS have been installed and IDCOL has set a new target of installing a total of 5 million ICS by 2023.

1.2 Literature Review

Combustion of various forms of fuel including solid, biomass etc. in traditional cook stoves are found causing substantial environmental and health damage that helped to generate the conventional wisdom of possible reduction of exposure to indoor air pollution, improve health outcomes, and decrease greenhouse gas emissions in the rural areas of developing countries through the adoption of improved cook stove (ICS) (e.g. Mobarak et. al. 2012; Hanna, Duflo and Greenstone, 2012). However, adoption of various types of ICS had faced significant challenges and impacts on welfare outcomes are also found to be mixed (e.g. Jeuland and Pattanayak, 2012). In a study on young Guatemalan children, Bruce et al. (2004) shows that stove/fuel type was the most important determinant of kitchen carbon monoxide (CO), with some effect of child position during cooking.

Studies on the impact of improved Cook Stoves in Rwanda, Uganda, Malawi, Nigeria and Kenya reveals a significant improvement of indoor air pollution (IAP) (with reduction in PM, CO) and health and educational outcomes (e.g. Kelly et al. 2018; Onyeneke et al.,2017; Rosa et. al. 2014; Ireri and Collings,2017; Ngeywo, 2009). The Ugandan case as depicted by Ireri and Collings (2017) identified a 42% savings in fuel expenditure as to be the primary benefit, on average in addition to reduction in forest destruction along with time savings and health benefits. In a study on the impact of Save80 Cook Stove in Kaduna, Nigeria; Onyeneke et al. (2017) found that Save80 significantly led to reductions in fuel wood consumption, fuel wood collection time, cooking time, carbon monoxide exposure, and incidence of sore eyes. With significant identifiable welfare gains from a green growth intervention, the authors suggest that Save80 cook-stove should be disseminated throughout the Savanna area of Nigeria where fuel wood consumption is highest in Nigeria. However, using mixed method, Kelly et al. (2018) assesses the impact of cook stoves on primary school absenteeism in Karonga district of northern Malawi and find no evidence that the cook stoves affected primary school absenteeism overall and did not sufficiently improve household health to influence school attendance as well.

A median reduction of 48% of 24-h PM2.5 concentrations in the cooking area has been identified by Rose et al. (2017) in the Rwandan case. In an assessment on traditional and improved stove use on household air pollution and personal exposures in two villages of rural western Kenya; Yip et al. (2017) observed a reduction in mean 48-hour $PM_{2.5}$ and CO concentrations compared to the traditional cook stoves despite concentrations for both pollutants were still consistently higher than WHO air quality guidelines. Their findings illustrate that ICS tested in real-world settings can reduce exposures to IAP, but implementation of cleaner fuels and related stove technologies may also be necessary to optimize public health benefits. However, Ngeywo (2009) found that improved institutional stoves reduced the 24-hour mean daily concentration of PM_{10} by 68% and CO by 75% compared to their traditional counterparts and ICS required 44% less fuel wood to complete the same cooking task as compared to traditional stoves.

In a review of World Bank's regional ICS program in Central America, Lambe and Ochieng (2015) reveals that most of the stoves demonstrate high performance; reducing fuel use and PM/CO emissions by at least 50%. Two studies on the impact of "Patsari" cook stove in rural Mexico exhibit significant health gains through reduced PM/CO concentrations (e.g. Masera et al. 2007; Romieu et al. 2009). In paired comparisons in a sub-set of kitchens in a single community before and after installation of an improved Patsari cook stove in Michoacan, Mexico, Masera et al. (2007) shows a 48-hour average kitchen concentrations of carbon monoxide (CO) and fine particulate matter (PM2.5) were reduced by around 66-67%. In another Mexican case, Romieu et al. 2009 demonstrates that women who reported using the Patsari stove most of the time compared with those using the open fire had significantly lower risk of respiratory symptoms with similar results for eye discomfort, headache, and back pain as well.

In a research on gender and livelihoods impacts of clean cook stoves in South Asia carried out by Practical Action (2014) exhibits that on average there is a 28.1% reduction in fire wood consumption due to the use of an ICS compared to a traditional cook stove (TCS) with women who use ICS, spend only 305 hours on fuel collection, saving approximately 70 hours per year. In the Indian context, Sharma and Jain (2019) find that deployment of ICS would help in improving the IAQ of the kitchen area by resulting in reducing the concentrations of PM10, PM2.5, PM1 and CO by 21–62%, 20–80%, 24–87% and 19–93%, respectively. The authors also highlighted that the kitchen characteristics significantly influence the accumulation of air pollutants, demonstrated by the results that the IAQ being worst in the case of enclosed kitchen, resulted in the highest exposure index values. In the similar context, on women empowerment, Sheikh's (2014) results reveal that ICS use has a statistically significant and negative effect on the amount of time women and girls spend on fuel collection and a statistically significant and positive effect on the likelihood of women's participation in side businesses.

1.3 Objective of the Study

The main objective of this study is to assess the socio-economic benefits of improved cook stove (ICS) program of IDCOL. The specific objectives of the study are to gather information on basic household characteristics, kitchen characteristics, cooking pattern by individual stoves, fuel acquirement features etc. that are associated with ICS adoption. Moreover, information regarding various illnesses, with emphasis on respiratory, eye and gastrointestinal problems and related health costs/expenditure, efficient use of additional time in achieving adult/children educational outcomes, indoor air quality and other social activities has been accumulated using separate modules.

1.4 Organization of the Report

The report has been organized as follows: Chapter 2 clarifies the survey design methodology while the background characteristics of the sample households and issues related to fuel consumption, kitchen and cook stove use have been described in Chapters 3 and 4 respectively. Impact Assessment of the ICS intervention with outcomes has been detailed in Chapter 5 with concluding remarks along with recommendations have been outlined in Chapter 6.

CHAPTER 2: METHODS AND APPROACHES

2.1 Sample Survey

The sample size determination formula provides the minimum required sample size for estimating proportion in large size population as follows,

$$n = z^2{}_{\alpha/2} \frac{p(1-p)}{d^2} \times f,$$

where,

p is the proportion of the required characteristics in the population based on hypothesis rather than observed facts, $z_{\alpha/2}$ the value of the standardized percentile allowing α probability of bad samples, d the allowable margin of error and f is the design effect used for complex surveys using multi-stage cluster sampling.

Conventionally, α can be taken as 0.05 and f can be taken as 1.5 to 2.0 for most socio-economic surveys in Bangladesh. For example, the improved cooking stove is new to many of the households, so theoretically, $p = 0.5$ gives the safest sample size since in this case $p(1-p)$ takes the highest value. A common choice for the value of the allowable margin of error is $d = 0.0025$. With $f = 2$ and considering anticipated non-responsive rate at 5% the above formula gives total sample size (household) to be is 768. Considering the same number of sample households from the control areas, we finally decided to collect samples for the ICS interventions as follows: Treatment: 1000 and control: 1000 households.

About 20% of the respondents were selected from each of the Khulna and Rajshahi divisions and 30% from Rangpur division. About 10% of the respondents were selected from each of the Dhaka, Barisal and Chittagong divisions (Table 2.1).

Table 2.1: Incidence of ICS Adoption by divisions

Division	Adoption (%)	Non-adoption (%)
Dhaka	10	10
Barisal	10	10
Chittagong	8	7
Khulna	20	25
Rajshahi	22	18
Rangpur	30	30
N	1000	1000

Source: BIDS Survey, 2018

2.2. Community Survey

In addition to household survey, community survey was conducted in both treatment and control areas. The community surveys use separate questionnaires for each of the interventions even if communities overlap among interventions. Community survey included basic village characteristics, access to various infrastructures, IGA activities, price of alternate fuels and consumers goods, etc. The sample size for community surveys has been decided upon consultation with IDCOL. In particular, one community survey was conducted from each of the villages where household survey was conducted. A total of 82 community surveys were conducted, of which 50 from treatment villages and 32 from control villages.

2.3. Development of Instrument

2.3.1 Reconnaissance Survey

Before developing the questionnaire for the improved cooking stoves survey, the IDCOL consultant and BIDS research team made a visit to Savar area where ICS intervention has already been made. The purpose of the survey was to see the possible changes that are being made in the area as well as coverage of ICS intervention. The team also got a first-hand experience on pricing and other administrative aspects of improved and characteristics of the beneficiary households.

2.3.2 Instruments

Both structured and semi-structured questions were incorporated in the questionnaires designed for both household and enterprise survey. The questions incorporated in the questionnaires were based on the objectives of the study. In addition, while designing the questionnaire, similar types of studies conducted in Bangladesh and outside Bangladesh were reviewed and also consulted with the Consultant of the IDCOL. Three modules of questionnaires for households, community and POs were designed. The questionnaires have broadly captured the following aspects.

Table 2.2: Key Issues in Specific Modules

Component	Specific Modules	Community Survey
ICS	- Household characteristics such as head's gender, age, education, household structure, sanitation etc. -Demographics of household member -Assets (Land, and non-land) -Education -Health condition -Household income (**in details**) -Household expenditure (**in details**) -Time used for women and children -Attitude and opinion -Decision making in the household -Cook stove usage	-Basic village characteristics -access to various infrastructures -IGA activities - price of alternate fuels and - consumers goods

2.4. Mobilization of Team

Formation of the survey team is the first step towards survey implementation. Team members have been hired based on their skills and experience in various aspects of the survey implementation process and a thorough knowledge of local and country-specific context. A database of professional enumerators and supervisors of about 100 with five years and more experience mostly in rural area surveys nationwide was reviewed for selection. From the database, 3 teams were formed consisting of 5 members including one supervisor in each of the team for the ICS surveys.

The supervisors and enumerators were recruited on the basis of their previous experiences on data collection and supervision. Minimum education qualification was graduation from social sciences or any other relevant subjects. For the supervisors, it was required to have at least five years of experience in field supervision activities. Supervisors were given the responsibility to supervise, coordinate, monitor and ensure validity of data collection. Also a data entry specialist and 10 data entry operators were recruited for entry, cleaning and processing of survey data. Table 2.3 highlights the responsibilities of various team members.

Table 2.3: Major Roles and Responsibilities of the Team Members

Team member(s)	Major roles
Research Team	• Ensures overall success of the data collection activities. • Participates in survey instrument development and recruitment of qualified enumerators • Leads interviewer training, and development of training materials. • Coordinate and synchronizes data collection and data entry efforts to finish them in a timely and efficient manner. • Is in charge of drafting the survey report.
Field Supervisors	• Explain the project to, and seek cooperation from, the community/local leaders of the selected villages. • Arrange interview appointments with households for the field enumerators with the help of village leaders. • Assign interviewing assignments to field enumerators, help them locate sample households, and manage field work . • Ensure collection and accuracy of data by monitoring field interviews, and reviewing completed questionnaires submitted by the field interviewers. • Conduct enterprise survey • Conduct community survey.
Field Enumerators	• Locate households and conduct surveys. • Ensure the accuracy and completeness of the collected data. • Consult with their supervisors to resolve any confusion and survey related issues as opposed to making decisions on their own. • Are prepared to revisit households if any missing or incomplete items are discovered in the questionnaires.
Data Entry Operators	• Enter data into the computer using standard statistical software • Validate entered data.
Data Cleaning and Estimation	• Clean the data to ensure internal consistency. • Derive estimates of descriptive statistics and conduct the tests of differences wherever applicable.

2.5. Training and Quality Control Measures

A two day-long extensive training program for the surveys were conducted for the preliminarily selected enumerators on the use of questionnaire. They were given adequate knowledge about RETs as well as selection of the respondents. Moreover, they were given instructions on how to collect different information from the households and enterprises. After the training, a **field-testing** of the questionnaire was done in two villages in Savar upazila of Dhaka on September 12, 2018. All the selected enumerators and supervisors were participated in the field-testing process.

2.6. Pretesting the Survey Instruments

Before administering each of the four surveys, pre-testing of the questionnaires was conducted. The objective of pretesting is to test the questionnaires and the overall preparedness of the survey team in conducting the actual survey. More specifically, pre-testing helps to identify if there is any problem in the questionnaire in terms of its language, logic and sequence. It is important to test whether a question, in the way it is phrased, is able to elicit the right response from the respondent. Pre-test gives a good opportunity to verify that. Also questions sequenced in right order (with proper skip pattern) and logic is likely to be answered more accurately than when they are not. Furthermore, pretesting ensures that the codes of close-ended questions are as exhaustive as possible; in particular, they take into account all the possibilities that are relevant to the country and local context. Moreover, pretesting provides the survey team personnel an opportunity to determine the expected duration for a household interview, and on that basis, the total time duration for conducting the whole survey can be estimated. Pretesting also provided the survey team an opportunity to evaluate the logistics and administration for the actual survey.

The pre-testing process was completed in two phases which are described below.

2.7. Preparation of the Survey Team

All the selected enumerators and supervisors had participated in the pre-testing process. Ideally, pre-testing is done in places away from the actual survey locations having similar conditions to actual survey areas. Considering the similarity of the households in actual survey areas, pre-testing was done in the Savar upazila of Dhaka on September 12, 2018.

The reason for selecting this district is that improved cook stoves are available in many of the households in this area and this is closer to Dhaka.

2.8. Administering Pretesting Interviews

Households selected for the pretesting were different from the ones selected for the actual surveys to ensure that pretesting does not influence or bias the households during the actual interviews. The survey team was provided vehicles for their transport to the specific villages, and they were equipped with necessary supplies as they would have been during the actual surveys, such as, the questionnaires, necessary authorization letters, and stationery. The BIDS representatives went to the villages to monitor pretesting interviews. Activities during the pretesting were including:

i. Carry out the interviews in entirety;

ii. Time calculation for each interview accurately, and make note of questions that take more than expected time;

iii. Check the questions for their logic, sequence and phrasing, and make note of questions that seem to confuse the respondents, make them hesitate or sensitive. Especially, all types of non-response should be carefully noted and distinguished, such as, “Do not know”, “Refuse to answer”, etc.; and

iv. Make note of categorical questions where the responses are outside the range of listed responses.

Pretesting for improved cooking stoves was done in the Savar upazila of Dhaka. The details of the pre-testing are given in Table 2.4.

Table 2.4: Information on Pre-Testing Survey Instruments

RETs	Pre-testing dates	No. of Treatment HHs interviewed	No. of control HHs interviewed	No. of communities interviewed	No. of POs interviewed	Name of villages/districts
ICS	12/09/2018	10	10	1	1	Villages: Monodia and adjacent village Union: Pathalia, Upazila-Savar, District-Dhaka.

CHAPTER 3: SOCIO-ECONOMIC AND DEMOGRAPHIC CHARACTERISTICS OF SAMPLE HOUSEHOLDS

This chapter describes the demographic characteristics, level of education, employment and occupation pattern, access to housing, water and sanitation, asset holdings, income, expenditure and energy consumption patterns, which are important to understand the adoption of ICS and draw valid inferences on the impact.

3.1 Demographic Characteristics of the Households

The demographic characteristics of the sample households depict the comparative scenario among different groups of adopters and non-adopters. The proportion of the female-headed households is higher in treatment groups (ICS adopters) compared to the control i.e. non-adopter households (6.5% vs. 5.8%). The general pattern of household size reveals no difference between the treatment and control group with the average being estimated at 4.38%. The sex ratio (male: female) is found to slightly significantly vary exhibiting 1.31 and 1.39 for both treatment and control groups consecutively that also signifies that there are more males in comparison to females in the overall sample households (Table 3.1).

Table 3.1: Demographic characteristics of the households

Indicator	Treatment	Control	Diff.	p-value
Sex ratio	1.31	1.39	-0.08	0.05
Age (Years) (Avg.)	28.40	27.92	0.48	0.23
Married (%) (for ages>=16)	53.42	52.53	0.89	0.69
Not currently married/never married (%)	41.92	42.96	-1.04	0.64
Proportion of female headed HH (%)	6.50	5.80	0.70	0.51
Household Size	4.38	4.38	0.00	0.99
N	1000	1000		

Source: BIDS Survey (2018).

The average age of the respondent is estimated to be around 28 years for both treatment and control groups. The results show that around 53.42% of the total respondents are currently married in the treatment groups and around 52.53% in the control groups. This is followed by the proportion not currently married and/or never married (41.92% vs. 42.96%).

Overall, both treatment and control groups are found to be quite similar in terms of the aforementioned demographic characteristics.

3.2 Education, Employment and Occupation

The findings reveal that about 81-85% of both the treatment and control household respondents have attended school for various periods of time. Among them, the proportion of primary school completion (30.06% vs. 31.34%) is considerably higher than secondary schooling (24.93% vs. 23.39%). However, the respondents having SSC and HSC levels were estimated to be quite similar for both treatment and control groups, albeit not significant (Table 3.2).

Table 3.2: Level of education and study time for individuals between ages five and above (%)

Schooling completed	**Treatment**	**Control**	**Diff.**	**p-value**
Never went to school	15.75	18.27	-2.53	0.13
Class I to Class V	30.06	31.34	-1.29	0.53
Class VI to Class IX	24.93	23.39	1.54	0.42
SSC Level	7.81	7.62	0.19	0.88
HSC Level	3.81	3.54	0.27	0.75
Trade course	0	0.02	-0.02	0.65
Religious schools/madrasa	0.93	0.95	-0.03	0.95
Undergraduate to Post Graduate	4.33	2.88	1.45	0.08
Total N	1000	1000		
For individuals attending school				
Percentage of children (aged 5-18) currently attending school	26.84	26.66	0.18	0.85
Time spent studying in the house per day (avg. min/day)	143.20	140.63	2.57	0.45

Source: BIDS Survey (2018).

Regarding employment status, the findings suggest that on average, the majority of the respondents among the treatment and control groups are employed. Among the respondents, business (22.5% vs. 17.30%), self-employed in agriculture (16.5% vs. 20.20%), salaried employee (12.5% vs. 7.6%) are prominent (Table 3.3).

Table 3.3: Employment by Occupation (%)

Employment category (%)	Treatment	Control	Diff.	p-value
Wage laborers in agriculture	7.80	12.50	-4.70	0.00
Wage laborers in non-agriculture	8.90	9.60	-0.70	0.59
Salaried employee	12.50	7.60	4.90	0.00
Self-employed in agriculture	16.50	20.20	-3.70	0.03
Self-employed in non-agriculture	1.80	4.00	-2.20	0.00
Transport owner/Business	5.30	5.90	-0.60	0.56
Fisherman	2.00	1.50	0.50	0.39
Carpenter/Meissonier/Weaver	5.70	7.00	-1.30	0.23
Various repair work	0.50	0.40	0.10	0.74
Contractor	0.20	0.00	0.20	0.16
Hawker/Barber	0.40	0.50	-0.10	0.74
Business	22.50	17.30	5.20	0.00
Tailor	0.50	0.70	-0.20	0.56
Self-employed professionals	1.30	0.90	0.40	0.39
Other self-employment	3.60	3.30	0.30	0.71
Total	1000	1000		

Source: BIDS Survey (2018).

3.3 Housing, Water and Sanitation Facilities

This section highlights housing, water and sanitation status of the surveyed households. Tables 3.4 and 3.5 displays the household and dwelling characteristics including materials used for the main dwelling for the treatment and control groups respectively. In Table 3.4, it can be seen that majority of the respondent dwell in their own house. The average number of rooms excluding the bathrooms, storage and cow sheds is slightly higher in treatment households compared to control households. Regarding the access to hygienic sanitation, the treatment households consist of 59.90% which is significantly higher than the control households of 50.80%.

Table 3.4: Housing and dwelling characteristics of the households

Categories	Treatment	Control	Diff.	p-value
Category of home ownership (%)				
Owned	94.60	95.20	-0.60	0.54
Rented/leased	3.20	1.20	2.00	0.00
No rent	2.20	3.60	-1.40	0.06
Number of rooms (excluding the bathroom, storage and cowshed)	2.38	2.28	.10	0.02
Access to hygienic sanitation	59.90	50.80	9.10	0.00
Access to arsenic free Tube-well	38.90	39.00	-0.10	0.96
N	1000	1000		

Source: BIDS Survey (2018).

Table 3.5: Materials used for the main dwelling (%)

Material Type	Treatment	Control	Diff.	p-value
Floor				
Mud	72.40	82.40	-10.00	0.00
Brick/Cement	27.60	17.60	10.00	0.00
Walls				
Mud	14.20	20.90	-6.70	0.00
Bamboo/Thatched/Straw/Jute stick/Timber	6.70	9.00	-2.30	0.06
CI sheet (Tin)	38.80	39.80	-1.00	0.65
Brick/Cement	40.30	30.30	10.00	0.00
Roof				
Bamboo/Thatched/Straw/Jute stick/Timber	6.70	9.00	-2.30	0.06
CI sheet (Tin)	89.30	92.50	-3.20	0.01
Brick/Cement	9.50	6.50	3.00	0.01
Tally	0.30	0.20	0.10	0.65
Total	1000	1000		

Source: BIDS Survey (2018).

Table 3.5 presents data on the construction materials used for floor, walls and roof. It shows that only 27% in treatment and 18% in control households, floor is made of brick/cement and the difference is statistically significant. Most of the households have mud-floor. For walls and roof, the most widely used material is brick/cement and CI sheet (Tin) consecutively. Overall, on average around 89.30% of treatment households use CI sheet on roofs compared to 92.50% of the control households. In the case of walls around 40.30% of the treatment households use brick/cement compared to the control households of 30.30%. This particular finding also appears to be statistically significant in both cases of walls and roof.

3.3.1 Electricity Access

The survey results show that over 90% of the surveyed households have access to electricity. The treatment households (96.90%) are found to have a significantly better access to electricity than the control households (94.80%). The major source of electricity used was grid electricity, followed by solar home systems (3.7% vs. 3%). Moreover the treatment groups have been using electricity for about 10 years (116.50 months) whereas control groups have been using electricity for about 8 years (97.78 months). This implies that most of the ICS adopters have access to electricity for quite a long time (Table 3.6).

Table 3.6: Households access to Electricity

	Treatment	Control	Diff.	p-value
HHs with access to electricity (%)	96.90	94.80	2.10	0.02
Main source of Electricity (%)				
Grid	93.10	91.80	1.30	0.27
SHS	3.70	3.00	0.70	0.38
Other	0.10	0.00	-0.10	0.32
Average length of time the following source has been used (months)				
Grid	116.50	97.78	18.72	0.00
SHS	57.32	65.83	-8.51	0.42
Other*	48.00			

Source: BIDS Survey (2018).
Note: *Other represents one (1) case only.

3.3.2 Drinking Water Sources

Table 3.7 shows that the main source of drinking water for household members is tube wells without arsenic inspection. The treatment households (around 50%) have higher access to the main source of drinking water than the control groups at around 48.10%.

Table 3.7: Principle sources of drinking water (%)

Sources of Drinking Water	Treatment	Control	Diff.	p-value
Tube well (arsenic contaminated)	5.50	5.20	0.30	0.77
Tube well (no arsenic contamination)	38.90	39.00	-0.10	0.96
Tube well (arsenic contamination not checked)	50.00	48.10	1.90	0.40
Pond/river/canal	0.00	1.30	-1.30	0.00
Supply water (piped water)	2.10	3.00	-0.90	0.20
Ring Well	0.10	0.00	0.10	0.32
Other	3.40	3.40	0.00	1.00
Total N	1000	1000		
If the source is tube well				
Deep tube well	82.84	81.37	1.47	0.41
Shallow tube well	17.16	18.63	-1.47	0.41
Total N	944	923		

Source: BIDS Survey (2018).

Only a meager number of control households (1.30%) are found to use water sources from pond, river and canal with no respondents were found among the treatment households.

3.3.3 Sanitation Facilities

In regard to types of latrine used by the respondents, majority of the respondents use the ring slab (water sealed) in both treatment and control groups (39.10% vs. 38.70%), followed by ring slab (water not sealed) (24.70% vs. 33.40%), sanitary latrine with septic tank (20.80% vs. 12.10%), ordinary pucca (9.60% vs. 6.70%), kacha without septic tank (4.30% vs. 6.60%) and bush/open space and other latrines (1.50% vs. 2.50%) for the overall treatment and control groups consecutively (Table 3.8).

Table 3.8: Types of latrine the households Use (%)

Types of Latrine	Treatment	Control	Diff.	p-value
Sanitary latrine with septic tank	20.80	12.10	8.70	0.00
Ring slab (water sealed)	39.10	38.70	0.40	0.85
Ring slab (water not sealed)	24.70	33.40	-8.70	0.00
Ordinary pucca	9.60	6.70	2.90	0.02
Kacha (without septic tank)	4.30	6.60	-2.30	0.02
Bush/open space/Other	1.50	2.50	-1.00	0.11
Total N	1000	1000		

Source: BIDS Survey (2018).

3.4 Household Assets

Table 3.9 reports the self-reported valuation of assets at current prices when the households were asked to estimate the value of their owned assets. The results suggest that treatment households accrue significantly higher assets than control households.

Table 3.9: Types and Value of Assets (in Tk)

Types of Asset (Tk)	Treatment	Control	Diff.	p-value
Homestead land (land only)	433260.9	336410.5	96850.4	0.00
Agricultural land	635362.8	504449	130913.8	0.08
Other land (Non-agricultural and others)	52348.5	27491.5	24857	0.02
Value of the dwelling house (excluding the homestead land)	135834.4	100217.5	35616.9	0.00
Buildings/structures/go downs/warehouse/ shops (used for own income generation activities, residential purpose, commercial purpose, others)	3073.2	1292	1781.2	0.11
Total assets	1259880	969860.5	290019.3	0.00

Source: BIDS Survey (2018).

Agricultural land appears to be the main valuable asset of the households (Tk. 635362.8 vs. Tk. 504449) followed by homestead land (Tk. 433260.9 vs. Tk. 336410.5), value of the dwelling house (Tk.135834.4 vs.Tk.100217.5) and non-agricultural and other land (Tk. 52348.5 vs. Tk. 27491.5) for overall treatment and control groups respectively. Overall, the treatment households hold assets worth significantly higher than those of the control households i.e. Tk. 1259880 vs. Tk. 969860.5 respectively. That is, ICS adopters are apparently better-off compared to non-adopters.

3.5 Poverty Status of the Households

In this section we attempt to assess poverty scenario of the surveyed households. For this purpose, we have used the conventional *Foster, Greer, and Thorbecke (1984)* technique, dubbed as the FGT method.[1] Table 3.10 presents estimates of all three measures of

[1] Poverty (as well as extreme poverty) is measured with the help of three indices–namely, (a) the headcount poverty index (P_0), which measures the proportion of the population counted as poor, i.e., whose consumption expenditure falls below the poverty line (b) the poverty gap index (P_1), which measures the average depth of poverty, i.e. on average, how far below the poverty line the poor people's consumption happens to lie and (c) the squared poverty gap index (P_2), which also measures the average depth of the poverty but it is a weighted average; with greater weights being assigned to the gaps of the poorer persons. As the headcount poverty rate gives only the percentage value of poverty incidence and does not measure the distance of the poor

poverty among the treatment and control groups across the types of intervention envisaged. The estimates reveal the process of accelerated poverty reduction in the rural areas. The headcount rate, using the upper poverty line[2] has been estimated at 11.70% for treatment groups and 16.10% for control groups. However, using the lower poverty line, it can be seen that the proportion of poor is estimated at 4.90% for treatment groups and 5.30% for control groups.

Table 3.10: FGT Measures of Poverty Based on Expenditure

FGT Indices	Treatment	Control	Diff.
Upper (Moderate) Poverty Line			
Headcount	11.70	16.10	-4.40
Poverty Gap	0.10	0.10	0.00
Squared Poverty Gap	0.55	0.52	0.03
Lower (Extreme) Poverty Line			
Headcount	4.90	5.30	-0.40
Poverty Gap	0.10	0.00	0.10
Squared Poverty Gap	0.17	0.12	0.05

Source: Authors' calculations.

Using the upper poverty line, the poverty gap has been estimated at 0.10% for treatment households and 0.10% for control households. Similarly, using the lower poverty line, the poverty gap has been estimated at 0.10% for treatment groups and 0.00% for control groups. The squared poverty gap measures the severity of poverty. Using the upper poverty line, the squared poverty gap has been estimated at 0.55% in the case of treatment households and 0.52% in the case of control households. Using the lower poverty line, the squared poverty gap has been estimated at 0.17% for treatment groups and 0.12% for control groups. Thus, better-off households appear to adopt ICS at a higher proportion.

households from the poverty line, the poverty gap estimates about the depth and severity of poverty of the population are required.

[2] The upper and lower poverty lines through updates of BBS 2016 estimates were used in head counts i.e. the poverty line is set at 1862 units (lower) & 2268 units (upper).

3.6 Summary

The findings regarding the basic socio-economic characteristics reveal that on the whole, the treatment and control households are quite similar with regards to the demographic characteristics, level of education, employment and occupation pattern, access to housing, water and sanitation, asset holdings, income, expenditure and energy consumption patterns. For example, the average age of the respondents (mainly the main woman) is about 28 years for both treatment and control groups. More than 50% of the total respondents, mostly who are women, are currently married. About 95% of the sample households have access to electricity. both the treatment and control groups are comparable in terms of their educational attainment and results depict that around 26.84% and 26.66% of school going children spend an average of around 143.20 min./day and 140.63 min./day in treatment and control households consecutively. On the benefit side, non-ICS adopter households are found to suffer from coughing, breathing, eye irritation, and headache at a higher proportion than the treatment households indicating a positive health impact of ICS. Overall, both treatment and control groups are found to be quite similar in terms of their demographic and other socio-economic characteristics as well. It is also revealed that better-off households appear to adopt ICS at a higher proportion.

CHAPTER 4: ISSUES RELATED TO FUEL CONSUMPTION, KITCHEN AND COOK STOVE USE

This Chapter looks into issues related to fuel consumption, kitchen characteristics and cook stove use, ICS perception and promotion, average time use for women and their income-generating activities. ICS is expected to save time with regards to cooking and fuel collection, save money and reduce costs and facilitate women to perform more income-generating activities through average time savings from household chores etc. As an important proportion of households use both ICS and traditional stoves simultaneously, we try to explore the characteristics for both the groups—only ICS users and ICS plus traditional stove users, in some cases.

4.1 Types of Cook Stove Use

Various types of cook stoves are found to be used by both treatment and control groups and the findings are displayed in Table 4.1 below. It appears that only 28% households use only ICS while a good proportion of ICS adopters (about 72%) simultaneously use traditional stoves, gas stoves etc.

Table 4.1: Types of Cook Stove Use

Category	Treatment			Control	Diff.	p-value
Type of stove	ICS Only	ICS with others	Overall			
With open fire (3 or 5-stone stove)	0	0.42	0.30	0.50	-0.20	0.48
Traditional mud stove	0	74.06	53.10	99.10	-46.00	0.00
Gas stove	0	29.15	20.00	10.80	9.20	0.00
Rice cooker	0	7.53	5.40	3.80	1.60	0.09
ICS	100	100	100	0.00	-100	0.00
Other	0	2.65	2.00	0.40	1.60	0.00
Respondents proportion (%)	28.3	71.7				

Note: Multiple responses are reported; **Source:** BIDS Survey (2018).

The findings show that about 53% of the treatment households are found to utilize traditional mud stove beside ICS compared to around 99.10% of the control households who are still traditional mud stove users. About 20.00% of the treatment households are found to use gas stove which is significantly higher than the control households (i.e. 10.80%).

4.2 Characteristics of Household Kitchen

Table 4.2 shows the location of the cooking area, its position in the adjacent areas of the house and the size of the kitchen for both treatment and control groups. The findings show that most of the households among the treatment and control groups have a separate kitchen room inside their main house (68.80% vs. 63.90%) and is significantly higher for the treatment group compared to the control group.

Table 4.2: Characteristics of Household Kitchen

Location of the cooking area	Treatment			Control	Diff.	p-value
	ICS Only	ICS with Gas & Kerosene stove	Overall			
Outside the main house, separate kitchen (covered all around)	6.71	6.80	6.70	9.50	-2.80	0.02
Outside the main house (uncovered i.e walls but no roof)	0	0.29	0.20	0.40	-0.20	0.41
Separate kitchen (uncovered i.e. no walls but connected roof)	14.84	9.99	11.30	10.20	1.10	0.43
Separate kitchen (uncovered i.e. no walls and no roof)	9.89	6.37	7.50	9.50	-2.00	0.11
In the main house (separate room)	65.02	70.33	68.80	63.90	4.90	0.02
Outside the main house, sharing common wall	1.41	4.63	3.70	4.00	-0.30	0.73
Outside the main house, sharing common roof (open in 1 or 2 sides)	1.06	1.01	1.00	1.30	-0.30	0.53
In the main house (common with dining area),	0	0	0.50	0.80	-0.30	0.40
In the main house (common with sleeping area)	0	0	0.10	0.10	0.00	1.00
Other	1.06	0.58	0.8	1.2	-0.4	0.37
Average length of the kitchen (ft)	8.25	8.73	8.59	8.50	0.09	0.46
Average width of the kitchen (ft)	6.01	6.36	6.25	6.25	0.00	0.96
Average height of the kitchen (ft)	6.71	6.89	6.85	6.72	0.13	0.06
The number of ventilation pathways present other than the kitchen door/opening (no.)	1.48	1.52	1.51	1.56	-0.05	0.25

Source: BIDS Survey (2018).

This is followed by separate kitchen (uncovered i.e. no walls but connected roof) where treatment households reported 11.30% compared to 10.20% of the control households, although the difference is not statistically significant. However, 9.50% of the control households reported their kitchen locations outside the main house but separate kitchen covered all around which is significantly higher than the respondents of the treatment households (i.e. 6.70%). Again, 9.50% of the control group reported separate kitchen (uncovered i.e. no walls and no roof) that is not significantly higher than the treatment group (7.50%). The kitchen size indicators revealed an almost similar pattern for both treatment and control households and are represented by the average length (8.59ft. vs. 8.50ft), width (6.25ft. vs. 6.25ft) and height (6.85ft. vs. 6.72ft) of the kitchen respectively. As most of the kitchen is within the house, it is highly expected that kitchen smokes can affect health conditions of the household members.

4.2.1 Cooking Time

In line of understanding the patterns of cooking time on a weekly basis, the respondents were asked to report the average time spent (minutes) of their cooking time of different meals and the findings are displayed in Table 4.3. The findings show that ICS requires relatively less time for cooking across different meals. The time difference between for meal cooking between the groups is statistically significant.

Table 4.3: Status of Cooking Time

Time spent on cooking meals/using the stove (minutes/week)	Treatment			Control	Diff.	p-value
	ICS Only	ICS with Gas & Kerosene stove	Overall			
Breakfast	64.27	62.26	62.65	78.62	-15.97	0.00
Lunch	79.00	80.00	79.69	97.09	-17.41	0.00
Dinner	59.82	54.53	55.94	67.34	-11.40	0.00
Other meals	19.18	21.40	21.08	21.55	-0.47	0.60
Other use (e.g. boiling water)	18.53	21.93	21.47	21.38	0.09	0.95
Preparing the stove before using (setting up the fuel and lighting up)	8.07	7.47	7.59	9.00	-1.41	0.00
Cleaning the stove after cooking	6.54	5.97	6.12	7.16	-1.04	0.00

Source: BIDS Survey (2018).

The time spent on preparing the stove before using and cleaning the stove after cooking seems to differ significantly for both the treatment and control groups. While the control households need an average of 9.00 minutes, the treatment households need around 8 minutes and saves 1 minute, which is statistically significant.

4.3 Impact of ICS Adoption

4.3.1 ICS Saves Time for Fuel Collection

Features of fuel collection/purchase and time spent have been reported in Table 4.4. Every month, the treatment households collected firewood 4.27 times compared to the average of 4.36 times for the control households. This seems to exhibit almost an equal pattern despite being insignificant. The results indicate that ICS requires less time on fuel collection/purchase, as expected because of less amount of fuel/firewood is required and therefore saves time. On the other hand, although insignificant, ICS reduces frequencies of fuel collection/purchase.

Table 4.4: Features of Fuel collection/purchase and time spent

Fuel source	Treatment			Control	Diff.	p-value
	ICS	ICS with Gas & Kerosene stove	Overall			
Average Number of times per week firewood was collected (every month)	4.52	4.19	4.27	4.36	-.09	0.65
Avg. amount of time spent for each collection (min)	60.53	57.92	58.91	62.51	-3.60	0.02
Avg. amount of time spent per month for collection (min)	273.60	242.68	251.55	272.54	-21.00	0.02
Avg. number of times fuel was purchased (every month)	0.92	0.73	0.79	0.86	-0.07	0.15
Avg. amount of time spent on each purchase (min)	79.15	72.19	74.04	81.73	-7.69	0.02
Avg. amount of time spent per month for purchase (min)	72.82	52.70	58.49	70.29	-11.80	0.02

Source: BIDS Survey (2018).

4.3.2 ICS Saves Money / Reduce Costs

ICS saves money and reduces costs. On average, the respondents (i.e. ICS and non-ICS adopters) reportedly are found to use firewood/twigs as their primary fuel for cooking and parboiling purposes. Average consumption of firewood/twigs is estimated to be around 95.30 kg for the treatment group and is significantly higher compared to control group's consumed quantity of 85.83 kg. However, only for the ICS users, it is estimated at 87.47 kg. Consumption of animal waste/dung/cake (27.84 kg vs. 33.98 kg) and tree leaves (24.70 kg vs. 31.63 kg) are found to be significantly higher for the control group than those of the ICS households (treatment). This pattern has also been similarly followed by crop residue/husk (7.00 kg vs. 13.91 kg) and jute stick (4.06 kg vs. 5.34 kg) where the average consumption of the control households is reported to be significantly higher than that of the treatment households. Overall, except the firewood/twigs, all other types of fuels were less consumed in ICS households, indicating that ICS reduces fuel expenses.

Table 4.5: Types of cooking fuel consumed, costs and usage

Category	**Treatment**			**Control**	**Diff.**	**p-value**
Average consumption of fuel per month	**ICS**	**ICS with Gas & Kerosene stove**	**Overall**			
Firewood/twigs (kg)	87.47	98.15	95.30	85.83	9.47	0.00
Animal waste/dung/cake (kg)	30.84	24.50	27.84	33.98	-6.14	0.01
Tree leaves (kg)	21.31	25.97	24.70	31.63	-6.94	0.00
Sawdust (kg)	1.59	0.64	0.93	0.75	0.18	0.64
Crop residue/husk (kg)	5.83	7.65	7.00	13.91	-6.92	0.00
Straw (kg)	0.14	0.84	0.62	1.14	-0.52	0.13
Bagasse (kg)	0.07	0.00	0.02	0.09	-0.07	0.42
Jute stick (kg)	6.27	3.16	4.06	5.34	-1.28	0.02
Charcoal (kg)	0.04	0.15	.197	.14	.057	0.69
Kerosene (liter)	0.09	0.08	0.09	0.10	-0.01	0.50
LPG (cylinder) (kg)	0.00	1.39	0.95	0.52	0.43	0.00
Biogas (taka)	0.00	0.81	.56	0	.56	0.03
Other (Specify)	0.18	0.23	.25	.162	.088	0.55
Coconut shell/ Areca catechu shell	0.00	0.17	.115	.222	-.107	0.15
Dry bamboo/kunchi	1.52	0.46	.75	.93	-.18	0.65
Average estimated value of the collected or self-produced fuel (tk.)						
For purchased fuel						
Avg. no. of days that the fuel lasts (days)	43.54	80.37	69.90	49.31	20.60	0.00
Average purchase value of fuel (tk) (each time)	414.88	852.66	724.75	526.02	198.71	0.00
Total amount of Costs incurred for acquiring fuels (Tk./month)	395.41	393.35	389.31	463.88	-74.58	0.00
Usage of fuels in different activities						
Percentage share of other fuels used for cooking/parboiling	99.28	22.94	99.15	99.39	-0.24	0.10
Percentage of kerosene used for cooking/parboiling	99.09	34.42	31.52	27.11	4.41	0.36

Source: BIDS Survey (2018).

The lasting of the fuel in terms of number of days indicates **fuel efficiency of ICS**. On average, fuel lasts around 69.90 days in the ICS (treatment) households than that of around 49.31 days lasting among the non-ICS (control) households with the difference being statistically significant. The total amount of costs incurred for acquiring fuels further revealed the **cost efficiency** pattern of the treatment (ICS) households. The survey findings show that the treatment group spent around Tk. 389.31 which is significantly lower than the control group's spending at Tk. 463.88 (Table 4.5).

4.3.3 Carbon Emission Reduction

We have estimated indoor air pollution (IAP) status of Improved Cook Stove (ICS) and Traditional Cook Stove (TCS) according to cooking time (BIDS Survey, 2018) and secondary information provided by Begum (2017). We have compared two measurement ratios of black carbon emission e.g. Particulate Matter (PM) 2.5 / PM 10 and Black Carbon (BC) / PM 2.5 with respect to number of cooking times per day for ICS and TCS adopters and the findings are displayed in Tables 4.6 and 4.7 consecutively.[3]

Table 4.6: Indoor Air Pollution (IAP) levels for Improved Cook Stoves

Sl No.	Types of ICS	Cooking time/day	ICS Adopters (%)	Fuel Type	PM2.5 / PM10 ratio	BC / PM2.5 ratio
1	Double Mouth with Chimney	3	30.00	Wood and saw dust	0.70	0.13
1	Double Mouth with Chimney	1	3.75	Wood and saw dust	0.73	0.14
1	Double Mouth with Chimney	2	61.25	Wood and saw dust	0.65	0.14
2	Potable Metallic	2	46.92	Saw dust	0.82	0.11
2	Potable Metallic	1	15.24	Wood	0.58	0.12
2	Potable Metallic	3	30.59	Wood and saw dust	0.73	0.16
3	Single Mouth with Chimney	2	56.25	Wood and saw dust	0.73	0.12

Source: Begum, Bilkis A. (2017) and BIDS Survey (2018).
Note: A meager number of households reported more than 3 cooking times which are not presented in this table.

The comparative findings show that for at least 30% of ICS adopters (double mouth with chimney) who cook 3 times per day are exposed to PM 2.5/PM 10 = 0.70 levels of IAP

[3] The methodology of these estimations has been discussed in Appendix-III.

compared to 24.58% of TCS adopters being exposed to PM 2.5/PM 10 = 0.72 levels. This finding is also found to be similar for measurement ratio BC/PM 2.5 = 0.13 for ICS adopters (3 times cooking per day) compared to TCS adopters (BC/PM 2.5 = 0.15) for the same. In both comparisons, the ICS adopters are found to be less exposed to IAP compared to the TCS users indicating substantial health benefits.

Table 4.7: Indoor Air Pollution (IAP) levels for Traditional Cook Stove

Sl No.	Types of ICS	Cooking time/day	TCS Adopters (%)	Fuel Type	PM2.5 / PM10 ratio	BC / PM2.5 ratio
1	Single Mouth	2	51.02	Wood and saw dust	0.72	0.18
1	Single Mouth	3	24.58	Wood and saw dust	0.81	0.15
1	Single Mouth	1	18.09	Wood	0.65	0.14

Source: Begum, Bilkis A. (2017) and BIDS Survey (2018).
Note: A meager number of households reported more than 3 cooking times which are not presented in this table.

Improved IAP levels are also found to exist for ICS adopters who cook 2 and 1 time each day. These situations are found to prevail for other types of improved cook stoves e.g. potable metallic and single mouth with chimney as well. In most cases, carbon emissions are found to be lower (as measured by PM 2.5/ PM 10 and BC / PM 2.5) for the ICS adopters compared to that of the TCS users.

4.3.4 Health Condition

Health condition is an important indicator for the adoption of ICS. The respondents' survey reveals that around 75.80% of the treatment households had suffered from coughing and sneezing compared to around 77.20% of the control households during the previous month. This illness is followed by breathing problem (32.10% vs. 36.50%), irritation of nose and throats (18.20% vs. 13.70%), chest pain (8.20% vs. 7.00%), eye irritation or itching (5.20% vs. 8.20%) and headache (1.90% vs. 2.80%). We observe that non-ICS adopters have been suffering from smoke-related diseases at a higher proportion than the ICS-adopters. Among these various illnesses, the differences between treatment and control groups are found to be significant in cases for breathing problem, irritation of nose/throats and eye irritation/itching (Table 4.8). Since traditional stoves are likely to generate higher amount of smokes, it might cause smoke related diseases at a higher proportion among the control group respondents.

Table 4.8: Health condition and expense status of household members (last one month)

Category	Treatment			Control	Diff.	p-value
Type of illness suffered by respondents (%)	**ICS**	**ICS with Gas & Kerosene stove**	**Overall**			
Coughing/sneezing	60.07	53.69	55.30	58.00	-2.70	0.22
Headache	23.32	32.56	30.20	35.10	-4.90	0.02
Breathing problem	6.71	8.25	7.80	6.90	0.90	0.44
Eye irritation/itching	15.90	13.89	14.60	11.80	2.80	0.06
Chest Pain	5.65	4.92	5.10	7.60	-2.50	0.02
Irritation of nose/throats	2.12	1.74	1.90	2.80	-0.90	0.18
Burned hand from cooking fire	0.35	0.43	0.40	0.90	-0.50	0.16
Shoulder pained from fuel collection	2.47	1.30	1.60	1.30	0.30	0.57
Average no. of days suffered (days)	12.28	13.55	13.17	12.58	.59	0.44
Percentage that have visited any healthcare facility	89.27	88.68	88.99	87.26	1.73	0.15
Total treatment cost (Tk)	615.09	726.71	690.43	652.63	37.80	0.57

Source: BIDS Survey (2018).

On average, the treatment households suffered around 0.40 days compared to around 0.90 days for the control households. It has further been revealed that a higher proportion of treatment respondents (1.70%) had visited some kind of healthcare provider for their physical ailment than that of control respondents (1.30%) which entailed a certain cost for these services. The total monthly cost for treatment is higher in the treatment group at Tk. 690.43 than the control group at Tk. 652.63, albeit not significant.

4.4 ICS Usage Features

The questionnaire survey allowed us to depict interesting features regarding ICS stove usage among the ICS adopters i.e. treatment group only that has been portrayed in Table 4.9.

Table 4.9: ICS Usage Features

Category	Treatment
Respondents that have ICS as their main stove (%)	82.37
Respondents that received training on usage and maintenance of this stove (%)	36.55
Type of exhaust system on the stove	
Chimney	11.16
Hood	28.49
No exhaust system	60.36
Percentage of respondents that clean exhaust system regularly (%)	10.06
No. of openings of the stove	1.09
Respondents that have a portable stove (%)	82.37
Respondents that have a fixed stove (%)	17.63
Respondents that clean their stoves regularly (%)	98.90
No. of days the stove is used (last week)	6.24
Main fuel used for the stove (%)	
Firewood/twigs	55.64
Animal waste/dung/cake	15.16
Tree leaves	17.79
Crop residue/straw/ husk	3.52
Jute stick	5.79
Others	2.10

Source: BIDS Survey (2018).

Among the ICS adopters; around 82.37% respondents are found to utilize ICS as their main stove. Among the ICS users, around 82.37% of the respondents possess a portable stove with 17.63% possessing the fixed ones. On average, the ICS has been used around 6.24 days per week. The treatment households were asked regarding the exhaust system and around 60.36% responded not to have any exhaust system. Nevertheless, 28.49% of the ICS adopters are found to have hood followed by chimney-based ICS as responded by 11.16% of the households. Around 98.90% and 10.06% of the treatment households regularly clean their stoves and exhaust system respectively. Interestingly, only around 36.55% of the ICS households are found to receive training on usage and maintenance of this stove.

The fuel usage pattern of the ICS adopted households revealed that around 55.64% of the users use firewood/twigs as their main fuel. This has been followed by tree leaves (17.79%), animal waste/dung/cake (15.16%), Jute stick (5.79%) and crop residue/straw/ husk (3.52%). A meager amount of kerosene (0.60%), charcoal (0.18%) and LPG e.g.

cylinder (0.12%) are also found to be utilized by the ICS users with around 0.42% using other fuels as well.

Table 4.10: Issues on Adopting ICS

Category	Treatment
Length of time ICS has been used (years)	1.47
ICS was acquired through the following means (%)	
Was Purchased	100
For purchased stove	
If purchased, amount paid (tk.)	236.13

Source: BIDS Survey (2018).

As displayed in Table 4.10, ICS has been used for about 1.48 years by the adopters (i.e. treatment) and almost 100% respondents were found to acquire ICS through purchase. The price of ICS is about Tk. 236.

4.5 Issues related to ICS Perception and Promotion

4.5.1 ICS Promotion

Various promotional activities have been undertaken by the sponsors and IDCOL to promote ICS. We tried to collect information on various promotional activities from the respondents. The findings suggest that around 90.90% of the treatment respondents got to know about ICS benefits from agent/worker of ICS POs, followed by neighbors, friends or relatives (84.50%), brochure and leaflets (62.10%). Though a substantial proportion of control households got to know about ICS, they did not adopt it. The reasons for not adopting are highlighted in the next section.

Table 4.11: ICS Promotional Activities

Category	Treatment	Control	Diff.	p-value
Sources of knowledge about ICS (%)				
Watched documentaries, short films or commercials on the benefits of ICS	16.40	1.80	14.60	0.00
Listened to radio programs on the benefit of ICS	34.50	17.90	16.60	0.00
Brochures/leaflets	60.50	25.00	35.50	0.00
Billboard or poster/wall in the village on the benefits of ICS	62.10	28.90	33.20	0.00
Attended demonstration or sensitization activity organized by a PO of ICS	28.00	2.20	25.80	0.00
Attended demonstration or sensitization activity organized by other NGO/entity	24.10	2.10	22.00	0.00
neighbors, friends or relatives explain to you benefits of ICS	84.50	57.20	27.30	0.00
agent/worker of ICS PO come to your house to explain benefits of ICS	90.90	13.20	77.70	0.00
Nearest agent location from your house (km)	7.91	8.49	-0.58	0.25
No. of ICS agents situated near 1 km of the village borders (no.)	1.04	2.20	-1.16	0.00

Source: BIDS Survey (2018).

4.5.2 ICS use related issues

Perceptions regarding ICS adoption from the treatment (ICS) households and reasons for non-adoption from the control households both from program and non-program villages had been captured from the questionnaire survey. The findings had been discussed in the following sections.

Table 4.12 demonstrates the findings on households' perception regarding adoption of ICS in program villages below. The results show that around 96.10% of the respondents have used ICS continuously since its adoption. The reasons for using ICS had been highlighted as relatively less fuel requirement (31.74%), faster cooking time (31.63%), less amount of smoke (18.68%), doesn't pollute the environment (11.98%) and good for the health (5.68%). The respondents also identified some problems during ICS usage; in particular, the shape of the stove opening isn't feasible/suitable (24.88%), black residue is formed under the pot (20.69%), the sieve used is not convenient/satisfactory (13.93%), there is smoke creation (12.72%), PO didn't give the chimney for the stove (6.28%), it is relatively expensive (2.17%) and others (19.32%). However, the striking aspects of the responses from ICS households were the reasons for stopping the usage of ICS in the middle. Around 46.15% of the treatment households mentioned that they cannot use large pieces of firewood which is followed by reasons such as certain foods take longer to cook (15.38%), needs too much maintenance (12.82%), cannot cook in large pots (7.69%), food does not taste good (2.56%) and others (15.38%).

Table 4.12: Households with ICS

Category	Treatment HHs
Reasons for using ICS (%)	
Less amount of smoke	18.68
Cooking time is relatively faster	31.63
Relatively less amount of fuel is required	31.74
Doesn't pollute the environment	11.98
Good for the health	5.68
Others	0.29
No. of years back that ICS was first used (years)	1.48
Respondents that have used ICS continuously since its adoption (%)	96.10
Reasons for stopping the usage of ICS in the middle (%)	
Cannot cook in large pots	7.69
Certain foods take longer to cook	15.38
Cannot use large pieces of firewood	46.15
Needs too much maintenance	12.82
Food does not taste good	2.56
Other	15.38
No. of ICS used so far (including the current ICS being used)	1.04
Respondents that would switch to traditional stoves if the current ICS gets damaged (%)	24.40
Major problems faced while using ICS (%)	
There is smoke creation	12.72
Black residue is formed under the pot	20.69
The sieve used is not convenient/satisfactory	13.93
It is relatively expensive	2.17
PO didn't give the chimney for the stove	6.28
The shape of the stove opening isn't feasible/suitable	24.88
Others	19.32

Source: BIDS Survey (2018). *multiple responses are counted.

Table 4.13 draws interesting comparative insights from control household respondents from both program and non-program villages that are displayed below. The findings suggest that the responses of the control households differed based on their locations in the program and non-program villages. It was found that around 5.20% of the control respondents in program villages have ever used ICS. Despite the fact that the control households are not expected to use ICS in non-program villages; the respondents revealed that around 60.93% of the control households have heard of ICS and around 85.87% of the respondents would adopt ICS if the program is introduced in their villages.

This information is perhaps important for policy-makers and evaluators with regards to ICS program expansion harnessing economic and social benefits. The control respondents in both the program and non-program villages had further identified reasons for not using and not accepting ICS respectively. Around 33.76% of the control households in the program villages mentioned that they cannot use large pieces of firewood compared to 17.92% of the same in the non-program villages. Among other identified reasons; around 11.32% of non-program village controls revealed that they cannot cook in large pots than that of 8.86% of program village control. This has been followed by factors such as ICS is expensive (9.70% vs. 10.38%), certain foods take longer time to cook (8.86% vs. 5.66%), needs too much maintenance (7.17% vs. 2.83%), already using a clean stove (3.80% vs. 6.60%), food does not taste good (0.84% vs. 1.89%) and other factors (27% vs. 43.40%) for control households in program and non-program villages consecutively. Some interesting patterns could be identified from the control respondents in program villages with respect to reasons to stop ICS usage in the middle. Around 23.08% of the control households mentioned that ICS is expensive despite the majority (around 69.23%) indicated some other reasons for their discontinuation.

Table 4.13: Households without ICS

Category	**Control HHs in Program villages**	**Category**	**Control HHs in non-Program villages**
Respondents that have ever used ICS (%)	5.20	Respondents that have heard of ICS (%)	60.93
		Respondents that would adopt ICS if introduced into their villages (%)	85.87
Reasons for not using ICS (%)		**Reasons for not adopting ICS (%)**	
Cannot cook in large pots	8.86	Cannot cook in large pots	11.32
Certain foods take longer to cook	8.86	Certain foods take longer to cook	5.66
Cannot use large pieces of firewood	33.76	Cannot use large pieces of firewood	17.92
Needs too much maintenance	7.17	Needs too much maintenance	2.83
Food does not taste good	0.84	Food does not taste good	1.89
ICS is expensive	9.70	ICS is expensive	10.38

Category	Control HHs in Program villages	Category	Control HHs in non-Program villages
Already using a clean stove	3.80	Already using a clean stove	6.60
Other	27.00	Other	43.40
Reasons for stopping the usage of ICS in the middle (%)			
Cannot use large pieces of firewood	7.69		
Food does not taste good			
ICS is expensive	23.08		
Other	69.23		
No. of ICS used before stopping usage	1		

Source: BIDS Survey (2018).

4.6 Income Generation from ICS

As depicted in Table 4.14, the respondents in the ICS households revealed that around 0.30% percentage of the households have at least one family member involved in the ICS business. Among ICS related activities, around 0.20% of the treatment (ICS HH) respondents got engaged in installing the ICS and a further 0.20% of respondents were involved in other ICS related activities besides installation and repair/maintenance. No pattern had been observed towards non-ICS households (N=250) as these questions were particularly targeted towards ICS households only.

Table 4.14: HH involvement in ICS related activities

Category	ICS Households	Non-ICS households	Diff.	P-value
HHs that have at least one family member involved in the ICS business (%)	0.30	0.00	0.30	0.39
ICS Related Activity				
To install the ICS	0.20	0.00	0.20	0.48
Others	0.20	0.00	0.20	0.48
Total N	1000	250		

Source: BIDS Survey (2018).

4.7 Average Time Use for Women

Table 4.15 displays the average time use for women in various household chores, activities during spare time and own income generating activities and business as reported by women household members from both ICS and non-ICS households. It is observed that ICS adopter women have relatively higher amount of time to be used other than cooking due to less time required for ICS stoves.

Table 4.15: Average time use for women in 24-hours except sleep (min)

Types of activities	ICS households	Non- ICS HHs	Diff.	p-value
Wage/salaried work	378.39	377.50	0.89	0.98
Own income-generating activities/business	95.74	99.35	-3.61	0.39
Household work/chores	96.90	96.15	0.75	0.77
Cooking/preparing meals/boiling water/cleaning stoves	181.38	200.14	-18.76	0.00
Preparing stoves before cleaning and cleaning stoves after cooking.	17.25	17.77	-0.51	0.19
Reading and studying	54.29	60.50	-6.21	0.73
Taking care of children (incl. bathing, feeding, dressing etc.)	89.03	84.91	4.12	0.33
Helping in children's study/homework	60.17	58.77	1.40	0.52
Watching television	110.00	107.68	2.32	0.46
listening to radio	60.00	97.50	-37.50	.
Socializing, visiting neighbors, friends, relatives, entertaining guests	66.69	65.70	1.00	0.55
Rest	86.28	85.26	1.02	0.51
Religious activities	61.68	63.84	-2.16	0.09
Total	700.02	695.51	4.51	0.48

Source: BIDS Survey (2018).

The findings suggest that on average, the treatment households spend approx. 378.39 minutes in wage or salaried work compared to 377.50 minutes usage by the control households. This information has been followed by watching television (110.00 min. vs. 107.68 min.), household work/chores (96.90 min. vs. 96.15 min.), women's own income-generating activities/business (95.74 min. vs. 99.35 min.), taking care of children including bathing, feeding, dressing etc. (89.03 min. vs. 84.91 min.), rest (86.28 min. vs. 85.26 min.), socializing, visiting neighbors, friends, relatives, entertaining guests (66.69 min. vs. 65.70 min.), religious activities (61.68 min. vs. 63.84 min.), helping in children's study/homework (60.17 min. vs. 58.77 min.), reading and studying (54.29 min. vs. 60.50 min.) and preparing stoves before cleaning and cleaning stoves after cooking (17.25 min. vs. 17.77 min.) for

ICS (treatment) and non-ICS (control) households consecutively. Interesting insights could be drawn from average time use pattern in activities such as cooking, preparing meals, boiling water or cleaning stoves. On average, the treatment households spend approx. 181.38 minutes which is significantly lower than the control households average time use of approx. 200.14 minutes for the same. This justifies the time savings due to usage of ICS which subsequently releases more time for income generating activities and other spare time use for women members of the treatment households.

4.8 Women's perception regarding ICS

The opinion of the respondents, of whom majority are women, strongly agree with most of the statements like smoke from firewood is harmful to health, cooking with firewood is not very convenient, cooking with firewood is expensive, collecting firewood is time consuming, face becomes dark due to smoke exposure, cooking with traditional stoves is time consuming and cooking with traditional stoves is tiresome**.** The differences are not statistically significant implying that they all are concerned about the issues that are related to traditional stoves. Only significant difference in opinion is observed in cases when they reluctantly agree, though the proportions are small.

Some positive statements regarding ICS are also tested. The results in Table A3 (see Appendix) shows that respondents ICS adopters highly agree with the beneficial outcomes of the ICS compared to traditional stoves. However, respondents disagree with the statements that ICS adoption increases the taste of food and social standing of the adopters.

4.9 Summary

In this Chapter, we attempt to look into issues related to fuel consumption, kitchen characteristics and cook stove use, ICS perception and promotion, average time use for women and their income-generating activities. Overall, the results depict that the total time for cooking meal had reduced significantly (i.e. 156.24 minutes) for ICS (treatment) households compared to non-ICS (control) households (i.e. 174.71 minutes) exhibiting about 20 minutes **time savings** of the ICS adopters. The findings further reveal that in the aspect of stove usage features i.e. preparing the stove before using and cleaning the stove after cooking, the control households use an average of around 9.00 minutes that is significantly higher than that of the treatment households which stands at around 7.59 minutes. The intriguing aspect among the patterns of the cooking time is the significantly lesser time requirement among the ICS adopters (treatment) compared to non-ICS (control) adopters for the major and other meals exposing significant value addition of ICS in terms of time savings. The results indicate that ICS adoption decreases time spent on fuel collection/purchase significantly and the saved time perhaps was used for other household purposes and income-generating activities. On the other hand, although insignificant, frequencies of fuel collection/purchase are also reduced for ICS adopting households.

On average, the respondents (i.e. ICS and non-ICS adopters) reportedly are found to use firewood/twigs as their primary fuel for cooking and parboiling purposes. Average consumption of firewood/twigs is estimated to be around 95.30 kg for the treatment group and is significantly higher compared to control group's consumed quantity of 85.83 kg. However, on average, all other types of fuels were less consumed in ICS households, indicating that ICS reduces fuel expenses. On average, the lasting of the fuel, in terms of number of days, exhibits **fuel efficiency pattern of ICS**. The total amount of costs incurred for acquiring fuels further revealed the **cost efficiency** pattern of the treatment (ICS) households. The survey findings show that the treatment group incurred around Tk. 389.31 which is significantly lower than the control group that stands at Tk. 463.88. ICS adopters are less exposed to CO emissions due to less smoke generation (0.70 vs 0.72; based on PM2.5 / PM10 ratio).

CHAPTER 5: IMPACT OF ICS ADOPTION: REGRESSION RESULTS

This study analyzes the impact of ICS adoption on households' kitchen related and health outcomes. The reason is that as we have already seen in Chapter 4 that ICS adopter households have been able to reduce cooking time, fuel time and frequency significantly compared to non-ICS adopter households. Health related outcomes are also better for ICS adopting households. Since the results obtained in earlier chapters are based on descriptive test statistics, it does not imply causality. Therefore, in this chapter we run regressions to assess the impact of ICS adoption on selected outcome variables.

Our econometric model specification is as follows:

$$Y_{ij} = \beta + \alpha_1 ICS_{(1,0)} + \alpha_2 X_{ij} + \alpha_3 V_j + \varepsilon_{ij} \quad (1)$$

Where, Y_{ij} represents cooking time, fuel collection time, fuel collection frequency, monthly kerosene use, days suffered from smoke-related diseases, income generation of women, average time use of women for household i in village j; ICS indicates a dummy variable i.e. if the household is an ICS adopter = 1, 0 otherwise; Xij denotes household-level characteristics (e.g. age, marital status, formal education, house ownership, land ownership, access to electricity, safe drinking water and sanitation); Vj indicates village-level characteristics which includes village population, households in village, village distance from Upazila sadar, landless (below 0.5 acre), marginal land holder (0.5-1 acre), small land holder (1-2.5 acre), medium land holder (2.5-7.5 acre), large land holder (7.5+ acre), average daily wage (male), farm, non-farm, average daily wage (female) etc. and ε_{ij} captures the error term.

Using the model Eq. 1, first we run OLS and IV regressions to assess the impact of ICS adoption on cooking time, fuel collection time, fuel collection frequency (monthly) and kerosene consumption. Table A1 in Appendix reports the results of OLS regressions. Since adoption of ICS and income or health outcomes involves simultaneous causality, therefore ICS adoption may suffer from endogeneity biases. There are several ways to tackle endogeneity biases. One approach is to use instrumental variables (IV) regression techniques to obtain convincing unbiased results. To encounter the endogeneity issue, instrumental variable regression techniques (2SLS and GMM) have been employed (Wooldridge, 2002; Hayashi, 2002). Two-stage endogeneity tests are done with two groups of variables. The first group of variables is control variables including firm characteristics, district and sub-district characteristics and sector-specific variables that are included in the second-stage estimation. The second group of variables is instruments that satisfy the orthogonality condition of IVs. Though finding an appropriate instrument especially in cross-sectional data is a challenging task, we carefully chose a few instrumental variables which strongly influence adoption of ICS but not the outcome variables. Four groups of instrumental variables are used: (1) Advertisement/publicity that attracted adoption: Documentary, short film or commercial; Leaflet or brochure; Poster or billboard; Sensitization by ICS PO; Sensitization by NGO; (2) Distance to PO office; (3) Nearest agent and (4) ICS agent within 1 km.

Table 5.1 reports the IV regression results. The results show that ICS adoption significantly reduces cooking time and fuel collection frequency. We have not found any impact of ICS on fuel collection time and actual fuel use.

Table 5.1: Impacts of Improved Cook Stove Adoption (IV Results)

VARIABLES	(1) Log Total Cooking time	(2) Log Fuel Collection Time	(3) Fuel Collection Frequency	(4) Actual Fuel Use
ICS	-0.0784***	-0.0605	-0.752*	-0.00268
	(0.0185)	(0.0459)	(0.454)	(0.00503)
Age	0.000933	0.00415**	-0.0165	-4.31e-05
	(0.000699)	(0.00179)	(0.0172)	(0.000191)
Marital status	0.0700**	0.0248	0.541	0.00589
	(0.0283)	(0.0724)	(0.697)	(0.00773)
Formal education	0.0339**	0.0783*	0.0266	0.00485
	(0.0166)	(0.0419)	(0.408)	(0.00452)
House ownership	0.0989***	0.0730	2.573***	-0.00434
	(0.0295)	(0.0828)	(0.727)	(0.00811)
Land ownership	0.000166***	0.000565***	0.00223	7.65e-06
	(6.40e-05)	(0.000156)	(0.00158)	(1.75e-05)
Access to electricity	0.0982***	0.0466	-1.361*	0.178***
	(0.0313)	(0.0789)	(0.766)	(0.00850)
Access to safe drinking water	-0.0255	0.129	0.184	-0.0161*
	(0.0313)	(0.0814)	(0.771)	(0.00859)
Access to sanitation	-0.0262	-0.157***	0.381	-0.00218
	(0.0244)	(0.0602)	(0.602)	(0.00667)
Total HH in village	0.000179***	-0.000150	-0.00236*	-5.51e-06
	(5.76e-05)	(0.000145)	(0.00142)	(1.57e-05)
Total people in village	-2.30e-05**	2.97e-05	0.000257	-3.56e-07

VARIABLES	(1) Log Total Cooking time	(2) Log Fuel Collection Time	(3) Fuel Collection Frequency	(4) Actual Fuel Use
	(1.05e-05)	(2.65e-05)	(0.000259)	(2.87e-06)
Landless	-2.46e-05	-0.000196	0.00207	-9.22e-05***
	(0.000118)	(0.000296)	(0.00290)	(3.22e-05)
Landowner (marginal)	7.80e-05	0.000314	0.00492	3.72e-05
	(0.000291)	(0.000721)	(0.00716)	(7.94e-05)
Landowner (small)	-0.000501	-5.21e-05	-0.0103	0.000151
	(0.000424)	(0.00105)	(0.0105)	(0.000116)
Landowner (medium)	-0.000511	-0.00120	0.0184*	-0.000179
	(0.000432)	(0.00110)	(0.0106)	(0.000118)
Landowner (large)	-0.0127***	-0.0126*	-0.0154	0.00202***
	(0.00262)	(0.00674)	(0.0644)	(0.000715)
Distance from upazila sadar	9.83e-05	0.00345	0.0449*	-0.000104
	(0.00103)	(0.00259)	(0.0252)	(0.000279)
Male farm wage	0.00117***	0.00194**	0.0174**	-0.000111
	(0.000318)	(0.000816)	(0.00783)	(8.70e-05)
Male non-farm wage	-0.000396	-0.00121*	-0.0123*	9.32e-05
	(0.000272)	(0.000695)	(0.00668)	(7.42e-05)
Female farm wage	-0.000264***	-0.000815***	-0.00350*	-6.11e-05***
	(7.81e-05)	(0.000200)	(0.00192)	(2.13e-05)
Female non-farm wage	0.000194	0.00106**	0.00235	5.34e-05
	(0.000162)	(0.000414)	(0.00397)	(4.41e-05)
Child farm wage	-0.000134	-8.28e-05	0.00856***	-4.60e-05
	(0.000132)	(0.000338)	(0.00323)	(3.59e-05)
Child non-farm wage	7.04e-05	-0.000132	-0.0111***	-2.21e-06
	(0.000121)	(0.000312)	(0.00294)	(3.26e-05)
Constant	4.636***	3.683***	2.361	0.832***
	(0.104)	(0.271)	(2.552)	(0.0283)
Observations	1,844	1,641	1,850	1,846
R-squared	0.206	0.064	0.045	0.226
F-Statistics	18.64***	4.66***	3.96***	23.16***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Under identification test: (χ^2)	1039.133***	954.543***	1045.07***	1046.805***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Weak identification test	292.587	279.845	295.209	297.166
	(20.25)	(20.25)	(20.25)	(20.25)
Over identification test: (χ^2)	125.573***	37.034***	18.26**	27.252***
	(0.0000)	(0.0000)	(0.0109)	(0.0003)
Endogeneity test: (χ^2)	9.884***	1.101	2.841*	0.154
	(0.0017)	(0.2941)	(0.0919)	(0.6947)

Source: Authors' Calculations
Note: Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Next, we attempt to assess the impact of ICS adoption on income generating activities (IGA), women average time use and number of days suffered from smoke related diseases. The results are reported in Table 5.2. Results suggest that ISC adoption significantly increase women's average time use, that is, the time a woman saves from cooking due to

ICS use, she can use that time for other purposes. However, we have not found the impact of ICS on IGA income and number of days suffered from smoke-related diseases.[4] The reason is that as descriptive statistics suggest, ICS does not generate any income through creating employment opportunities. Moreover, it is also difficult to draw inference from a cross-section data about the disease onset and its causality with ICS adoption. More rigorous and focused study on the impact of ICS on health aspects may be conducted in future.

Table 5.2: Impacts of Improved Cook Stove Adoption (IV Results)

VARIABLES	(1)	(2)	(3)
	IGA income	Women's average time use	Days suffered from Smoke related diseases
ICS	141.2	25.41***	-0.0804
	(95.56)	(9.456)	(0.0882)
Age	5.386	-2.713***	-0.00211
	(3.623)	(0.359)	(0.00334)
Marital status	74.34	-6.741	0.138
	(146.8)	(14.53)	(0.136)
Formal education	-42.94	36.26***	0.0856
	(85.89)	(8.499)	(0.0793)
House ownership	91.44	13.45	0.170
	(153.1)	(15.15)	(0.141)
Land ownership	0.396	0.0922***	-0.000157
	(0.332)	(0.0329)	(0.000307)
Access to electricity	291.1*	40.54**	0.00937
	(161.4)	(15.97)	(0.149)
Access to safe drinking water	-114.3	10.47	0.0615
	(162.3)	(16.06)	(0.150)
Access to sanitation	297.7**	-0.652	0.245**
	(126.7)	(12.54)	(0.117)
Total HH in village	0.328	-0.00964	0.000249
	(0.298)	(0.0295)	(0.000275)
Total people in village	-0.0797	0.00218	-3.79e-05
	(0.0545)	(0.00540)	(5.03e-05)
Landless	-1.631***	-0.0196	0.000269
	(0.611)	(0.0605)	(0.000564)
Landowner (marginal)	1.954	-0.0794	-0.00180
	(1.508)	(0.149)	(0.00139)
Landowner (small)	3.723*	0.197	-0.000124
	(2.202)	(0.218)	(0.00203)

[4] Additional health impact variables e.g. total number of disease-affected people, affected people based upon individual diseases have further been investigated and the results are reported in Appendix Table 1. The results are mostly negative, although not significant.

Landowner (medium)	-0.454	-0.498**	0.000257
	(2.239)	(0.222)	(0.00207)
Landowner (large)	27.45**	-2.042	-0.0102
	(13.57)	(1.343)	(0.0125)
Distance from upazila sadar	9.725*	1.339**	-6.72e-05
	(5.300)	(0.524)	(0.00489)
Male farm wage	-1.466	0.609***	0.00249
	(1.649)	(0.163)	(0.00152)
Male non-farm wage	0.553	-0.498***	0.000668
	(1.407)	(0.139)	(0.00130)
Female farm wage	0.249	-0.0536	-0.000833**
	(0.404)	(0.0400)	(0.000373)
Female non-farm wage	0.228	0.0701	0.000860
	(0.837)	(0.0828)	(0.000772)
Child farm wage	0.771	-0.217***	-0.000262
	(0.681)	(0.0674)	(0.000629)
Child non-farm wage	-0.653	0.134**	-0.000267
	(0.620)	(0.0613)	(0.000572)
Constant	34.91	675.2***	0.513
	(537.5)	(53.18)	(0.496)
Observations	1,850	1,850	1,850
R-squared	0.050	0.114	0.089
F-Statistics	4.05***	11.27***	7.97***
	(0.0000)	(0.0000)	(0.0000)
Under identification test: (χ^2)	1045.07***	1045.07***	1045.07***
	(0.0000)	(0.0000)	(0.0000)
Weak identification test	295.209	295.209	295.209
	(20.25)	(20.25)	(20.25)
Over identification test: (χ^2)	7.805	49.417***	51.308***
	(0.3501)	(0.0000)	(0.0000)
Endogeneity test: (χ^2)	0.031	22.013***	7.674***
	0.8595	(0.0000)	(0.0056)

Source: Authors' Calculations

Note: Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

CHAPTER 6: SUMMARY AND CONCLUSIONS

IDCOL's ICS Program was initiated in 2013 with the objective of increasing fuel efficiency and controlling indoor air pollution and deforestation. It aimed at installing 1 million stoves by December 2018. This has further established a strong base to achieve 100 percent coverage of improved stoves by 2030 in line with Bangladesh's Country Action Plan for Clean Cook stoves. ICS help to reduce GHG emissions and solid fuel use for cooking that improves daily life of women and children. IDCOL's ICS program has achieved its initial target of distributing one million ICS in January, 2017, almost two years ahead of the project completion period. IDCOL's R&D initiatives upgraded the stoves under the program from Tier 1(>=15%) to Tier 3 (>=35%) level of thermal efficiency.

This study carries out household surveys to estimate the socio-economic benefits of improved cook stove (ICS) program of IDCOL. A sample survey of 1000 households including 500 households from ICS adopters and 500 households from non-ICS adopters (control) was conducted in 2018 to assess the impact of ICS on household welfare.

The survey results show that the total time for cooking meal had reduced significantly (i.e. 156.24 minutes) for ICS (treatment) households compared to non-ICS (control) households (i.e. 174.71 minutes) exhibiting the **time savings** pattern of the ICS adopters. On average, the lasting of the fuel in terms of number of days exhibits **fuel efficiency of ICS**. On average, fuel lasts around 69.90 days for the ICS (treatment) households than that of around 49.31 days for the non-ICS (control) households with the difference being statistically significant. The total amount of costs incurred for acquiring fuels further revealed the **cost efficiency** pattern of the treatment (ICS) households. The survey findings show that the treatment group incurred around Tk. 389.31 which is significantly lower than the control group that stands at Tk. 463.88. ICS also reduces time for preparing and cleaning time compared to traditional stoves. ICS adopters are less exposed to CO emissions due to less smoke generation (0.70 vs 0.72; based on PM2.5 / PM10 ratio).

Among the ICS adopters; around 82.37% respondents are found to utilize ICS as their main stove. Among the ICS users, while about 82.37% of the respondents possess a portable stove, the rest 17.63% possessing the fixed ones. On average, the ICS has been used for about 6 days a week. About 60% ICS adopters do not to use any exhaust system. Nevertheless, 28.49% of the ICS adopters use ICS with hood and 11.16% use chimney-based ICS. Only around 36.55% of the ICS households are found to receive training on usage and maintenance of this stove.

The results show that about 96% of the respondents have been using ICS continuously since its adoption. The reasons for using ICS had been highlighted as relatively less fuel requirement (31.74%), faster cooking time (31.63%), less amount of smoke (18.68%), doesn't pollute the environment (11.98%) and good for the health (5.68%). The respondents also identified some problems during ICS usage; in particular, the shape of the stove opening isn't feasible/suitable (24.88%), black residue is formed under the pot (20.69%), the sieve used is not convenient/satisfactory (13.93%), there is smoke creation (12.72%), PO didn't give the chimney for the stove (6.28%), it is relatively expensive (2.17%) and others (19.32%). These issues need to be addressed to improve efficiency and usability of ICS.

Although large-scale dissemination of cleaning cooking solution has the potential of yielding co-benefits in terms of reduced fuel collection time, improved household health, better local environmental quality and regional climate; still only about a small proportion of the rural household are currently using ICS despite efforts of various organization to introduce clean cooking solution. The primary barriers seem to be lack of awareness and unsustainable funding to scale-up the activities and lack of functional viability for potential suppliers or manufacturers. The intervention activities for ICS would include raising awareness about fuel saving and health benefit of clean cooking research and development to enhance product quality supporting selected partner organizations (PO) to generate demand and facilitate enterprise creation so that household are motivated by ICS.

In sum, though ICS adoption brought some positive benefits to user households, still a large section of households use both traditional and ICS simultaneously. Use of both types of stoves affected the positive benefits of ICS. Some negative aspects of ICS were also reported by the respondents which need to be addressed. Further improvement of ICS addressing households concern is expected to generate higher benefits of ICS. More awareness building programs are also needed to popularize ICS in Bangladesh.

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APPENDIX

TABLE A1: Impacts of Improved Cook Stove (ICS) Adoption (OLS Results)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
VARIABLES	Total number of disease affected people	Coughing/ sneezing	Headache	Breathing problem	Eye irritation/ itching	Chest Pain	Irritation of nose/ throats	Burns from stove	Neck or shoulder pain[b]
ICS	-0.00614	-0.00229	-0.0333	0.0268*	0.0387	-0.0193	-0.0141	-0.00376	0.00105
	(0.0536)	(0.0414)	(0.0263)	(0.0139)	(0.0243)	(0.0125)	(0.00914)	(0.00490)	(0.00501)
Age	-0.00313	-0.00857***	0.00192	-0.000408	0.00263**	0.000507	3.76e-06	0.000124	0.000673**
	(0.00268)	(0.00195)	(0.00132)	(0.000841)	(0.00119)	(0.000773)	(0.000384)	(0.000198)	(0.000316)
Marital status	0.0851	0.0491	-0.0932	-0.0265	0.146***	-0.0356	0.0265***	0.00915***	0.00976
	(0.103)	(0.0738)	(0.0573)	(0.0307)	(0.0291)	(0.0317)	(0.00605)	(0.00348)	(0.0118)
Formal education	0.0628	0.0113	0.0189	-0.0198	0.0586**	-0.00731	0.00595	-0.00567	0.000722
	(0.0608)	(0.0473)	(0.0307)	(0.0174)	(0.0267)	(0.0158)	(0.00882)	(0.00627)	(0.00816)
House ownership	-0.0894	-0.151*	-0.0329	0.0362**	0.0505	0.0235	-0.00176	-0.00607	-0.00791
	(0.118)	(0.0900)	(0.0529)	(0.0182)	(0.0372)	(0.0227)	(0.0159)	(0.0109)	(0.0150)
Land ownership	-4.77e-05	-7.11e-05	-0.000105	5.97e-05	6.81e-07	8.62e-05	1.15e-06	1.24e-06	-2.04e-05*
	(0.000288)	(0.000200)	(0.000102)	(5.53e-05)	(9.09e-05)	(9.08e-05)	(3.21e-05)	(1.48e-05)	(1.06e-05)
Access to electricity	-0.0927	-0.0723	-0.0446	0.00353	0.0107	-0.0109	0.0235***	-0.00386	0.00124
	(0.132)	(0.0884)	(0.0590)	(0.0331)	(0.0705)	(0.0322)	(0.00556)	(0.0122)	(0.0137)
Access to safe drinking water	0.0433	0.0383	0.00299	-0.00400	0.00930	0.0125	-0.0217	-0.00555	0.0114***
	(0.109)	(0.0865)	(0.0624)	(0.0357)	(0.0614)	(0.0279)	(0.0214)	(0.0141)	(0.00409)
Access to sanitation	0.00622	0.0856	-0.0257	-0.0539**	0.0558	-0.0394	-0.0255	-0.00824	0.0174***
	(0.104)	(0.0722)	(0.0467)	(0.0264)	(0.0363)	(0.0297)	(0.0191)	(0.0109)	(0.00458)
Total HH in village	-2.50e-05	0.000165	-7.62e-06	-4.97e-05	-0.000142*	2.17e-05	1.25e-05	1.36e-06	-2.59e-05
	(0.000192)	(0.000163)	(9.62e-05)	(4.66e-05)	(7.59e-05)	(4.40e-05)	(2.94e-05)	(1.86e-05)	(2.54e-05)
Total people in village	2.21e-07	-3.42e-05	-1.50e-06	4.72e-06	2.42e-05*	-3.65e-06	5.83e-06	-2.14e-07	5.06e-06
	(3.59e-05)	(2.98e-05)	(1.78e-05)	(8.04e-06)	(1.43e-05)	(7.92e-06)	(5.19e-06)	(3.58e-06)	(4.36e-06)
Landless	0.000609	0.000446	0.000270	-0.000158	4.06e-05	-1.99e-05	1.08e-05	-1.09e-05	3.02e-05
	(0.000433)	(0.000352)	(0.000213)	(9.79e-05)	(0.000138)	(5.16e-05)	(8.64e-05)	(1.84e-05)	(2.79e-05)
Landowner (marginal)	-0.00146	-0.000349	-0.00119**	0.000175	0.000180	-5.13e-05	-0.000162	-8.08e-05*	1.54e-05
	(0.00104)	(0.000852)	(0.000495)	(0.000241)	(0.000363)	(0.000128)	(0.000168)	(4.53e-05)	(8.90e-05)
Landowner (small)	-0.000961	-0.00165	0.000810	-0.000169	-0.000128	6.13e-06	-4.22e-05	0.000194	1.38e-05
	(0.00149)	(0.00122)	(0.000730)	(0.000346)	(0.000602)	(0.000179)	(0.000186)	(0.000162)	(0.000157)
Landowner (medium)	0.000258	0.000326	0.000311	0.000475	-0.000509	-0.000278	0.000182	-0.000126	-0.000123
	(0.00146)	(0.00113)	(0.000762)	(0.000394)	(0.000670)	(0.000186)	(0.000296)	(0.000115)	(0.000118)
Landowner (large)	-0.00458	0.00221	2.85e-05	0.000542	-0.00677**	0.00118	-0.000597	-0.000250	-0.000925
	(0.00931)	(0.00727)	(0.00463)	(0.00225)	(0.00330)	(0.00179)	(0.000873)	(0.000463)	(0.000805)
Distance from upazila sadar	0.00183	0.00327	0.000169	-8.15e-05	-0.000416	-0.000560	-0.000294	-0.000227	-3.11e-05
	(0.00368)	(0.00304)	(0.00191)	(0.00107)	(0.00151)	(0.00103)	(0.000727)	(0.000444)	(0.000400)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
VARIABLES	Total number of disease affected people	Coughing/ sneezing	Headache	Breathing problem	Eye irritation/ itching	Chest Pain	Irritation of nose/ throats	Burns from stove	Neck or shoulder pain[b]
Male farm wage	0.00473***	0.00346***	-0.000807	0.000442	0.00212***	-0.000353	-9.40e-05	-8.67e-05	4.15e-05
	(0.00130)	(0.000974)	(0.000627)	(0.000372)	(0.000662)	(0.000294)	(0.000192)	(8.46e-05)	(0.000163)
Male non-farm wage	-0.00154	-0.00208***	0.000969*	-5.02e-05	-0.000844	0.000341	3.89e-05	5.34e-05	3.86e-05
	(0.00107)	(0.000791)	(0.000529)	(0.000299)	(0.000536)	(0.000254)	(0.000164)	(0.000106)	(0.000123)
Female farm wage	-0.000404	-0.000135	-0.000234	-1.47e-05	0.000310**	-0.000222***	-1.86e-05	-1.09e-05	-8.05e-05*
	(0.000300)	(0.000235)	(0.000150)	(7.94e-05)	(0.000142)	(8.25e-05)	(4.52e-05)	(2.22e-05)	(4.15e-05)
Female non-farm wage	-0.000333	-0.000224	0.000387	-0.000154	-0.000711**	0.000304**	-1.40e-05	-1.39e-05	9.23e-05
	(0.000610)	(0.000503)	(0.000302)	(0.000154)	(0.000304)	(0.000142)	(9.62e-05)	(4.51e-05)	(7.37e-05)
Child farm wage	-0.000930**	-9.60e-06	-0.000671***	-0.000193*	-0.000142	-9.31e-05	6.49e-05	-1.89e-06	0.000116
	(0.000465)	(0.000359)	(0.000237)	(0.000117)	(0.000206)	(0.000160)	(8.38e-05)	(2.69e-05)	(9.25e-05)
Child non-farm wage	0.000820**	0.000499	0.000288	8.81e-05	-1.99e-05	4.99e-05	2.13e-05	1.88e-06	-0.000109
	(0.000388)	(0.000306)	(0.000211)	(8.15e-05)	(0.000165)	(0.000139)	(7.68e-05)	(2.08e-05)	(8.84e-05)
Constant	0.529	0.577*	0.419**	0.0453	-0.576***	0.0870	0.0166	0.0438	-0.0844*
	(0.407)	(0.319)	(0.204)	(0.117)	(0.171)	(0.0939)	(0.0513)	(0.0333)	(0.0466)
Observations	1,850	1,850	1,850	1,850	1,850	1,850	1,850	1,850	1,850
R-squared	0.080	0.039	0.035	0.023	0.045	0.029	0.021	0.007	0.014

Source: Authors' Calculations.

Note: [a] Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

[b] Neck or shoulder pain from firewood collection/carrying.

Table A2: Respondent's (Women) perception regarding ICS adoption

Category	Treatment	Control	Diff.	P-value
Smoke from firewood is harmful to health				
Strongly agree,	87.80	85.40	2.40	0.12
Somewhat agree	10.20	13.10	-2.90	0.04
No opinion	1.90	1.40	0.50	0.38
Somewhat disagree	0.10	0.10	0.00	1.00
Strongly disagree	0.00	0.00	0.00	
Cooking with firewood is not very convenient.				
Strongly agree,	56.10	52.70	3.40	0.13
Somewhat agree	25.50	29.40	-3.90	0.05
No opinion	3.20	2.80	0.40	0.60
Somewhat disagree	9.60	10.70	-1.10	0.42
Strongly disagree	5.60	4.40	1.20	0.22
Cooking with firewood is expensive				
Strongly agree,	60.40	60.90	-0.50	0.82
Somewhat agree,	21.00	24.40	-3.40	0.07
No opinion	5.20	6.70	-1.50	0.16
Somewhat disagree	9.30	6.60	2.70	0.03
Strongly disagree	4.10	1.40	2.70	0.00
Collecting firewood is time consuming				
Strongly agree,	59.60	58.90	0.70	0.75
Somewhat agree,	23.10	25.30	-2.20	0.25
No opinion	6.20	5.40	0.80	0.44
Somewhat disagree	8.50	9.10	-0.60	0.64
Strongly disagree	2.60	1.30	1.30	0.04
The face becomes dark due to smoke exposure				
Strongly agree	64.30	63.50	0.80	0.71
Somewhat agree,	23.70	25.70	-2.00	0.30
No opinion	8.40	7.50	0.90	0.46
Somewhat disagree	3.10	2.40	0.70	0.34
Strongly disagree	0.50	0.90	-0.40	0.28
Cooking with traditional stoves is time consuming				
Strongly agree,	56.80	56.80	0.00	1.00
Somewhat agree	31.60	30.50	1.10	0.60
No opinion	4.70	3.70	1.00	0.27
Somewhat disagree	6.30	8.10	-1.80	0.12
Strongly disagree	0.60	0.90	-0.30	0.44

Category	Treatment	Control	Diff.	P-value
Cooking with traditional stoves is tiresome				
Strongly agree,	68.60	69.60	-1.00	0.63
Somewhat agree,	24.90	25.30	-0.40	0.84
No opinion	5.10	3.60	1.50	0.10
Somewhat disagree	1.20	1.40	-0.20	0.69
Strongly disagree	0.20	0.10	0.10	0.56

Source: BIDS Survey (2018).

Table A3: Opinion regarding merits of ICS use (only treatment group)

Cooking with ICS is better for health	**%**
Strongly agree,	81.00
Somewhat agree,	14.10
No opinion	4.70
Somewhat disagree	0.20
Strongly disagree	
Cooking with ICS is faster than doing it with traditional stove	
Strongly agree,	83.40
Somewhat agree,	14.80
No opinion	1.00
Somewhat disagree	0.70
Strongly disagree	0.10
Cooking with ICS is cheaper than doing it with traditional stoves	
Strongly agree,	78.40
Somewhat agree,	19.90
No opinion	1.2
Somewhat disagree	0.40
Strongly disagree	0.10
Cooking with ICS is safer	
Strongly agree,	70.50
Somewhat agree,	20.00
No opinion	8.80
Somewhat disagree	0.60
Strongly disagree	0.10
Cooking with ICS reduces drudgery	
Strongly agree,	58.80
Somewhat agree,	29.50
No opinion	7.20
Somewhat disagree	3.20
Strongly disagree	1.30

Cooking with ICS is better for health	%
Cooking with ICS is not convenient for all kinds of food	
Strongly agree,	4.50
Somewhat agree,	9.70
No opinion	5.70
Somewhat disagree	25.50
Strongly disagree	54.60
Cooking with ICS makes the food taste bad	
Strongly agree,	3.50
Somewhat agree,	5.40
No opinion	7.60
Somewhat disagree	34.80
Strongly disagree	48.70
Using ICS increases social standing in the community	
Strongly agree,	25.40
Somewhat agree,	23.70
No opinion	38.20
Somewhat disagree	11.80
Strongly disagree	0.90
Most of my neighbors use ICS	
Strongly agree,	41.10
Somewhat agree,	35.50
No opinion	15.80
Somewhat disagree	6.90
Strongly disagree	0.70

Source: BIDS Survey (2018).

Appendix-II:

Women's Income Generating Activities

It is assumed that women's affiliation in income-generating activities (IGAs) inside and outside home is an important indicator for women empowerment. The questionnaire survey recorded detailed information on women's engagement in various income-generating activities, time usage in IGAs and monthly net earnings out of IGA business inside and outside home and the results are shown in Table A4 below.

Table A4: Women's Income Generating Activities

Categories (%)	ICS households	Non- ICS HHs	Diff.	p-value
Engaged in IGA	57.40	59.90	-2.50	0.26
IGA at Home	98.61	99.17	-0.56	0.36
IGA outside home	1.74	0.83	0.91	0.17
Major Types of IGAs (%)				
Weaving and Tailoring	0.52	1.34	-0.81	0.15
Handicrafts	0.35	2.34	-1.99	0.00
Tobacco products	0.17	0.00	0.17	0.31
Grocery/stationary shop	0.87	0.67	0.20	0.69
tea stall/restaurant	0.35	0.00	0.35	0.15
Other shop	0.17	0.17	0.01	0.98
Making clothes	6.45	5.34	1.10	0.42
Rearing Livestock	62.72	61.10	1.62	0.57
Rearing poultry	54.18	50.58	3.60	0.22
Other	1.22	1.67	-0.45	0.52
Time you spent in IGAs (min/day)	99.41	101.02	-1.61	0.71
Monthly Net Earnings (Tk.)	1550.80	1234.27	316.54	0.00

Source: BIDS Survey (2018).

It is found that around 57.40% of the treatment households are engaged in IGAs compared to 59.90% of the control households. Among them, around 98.61% of the ICS households conducted IGAs at home compared to around 99.17% of the control households. A meager amount of IGA (1.74% vs. 0.83%) are seen to be conducted outside home by both ICS and non-ICS households. Among the numerous types of IGAs; around 62.72% of the treatment group reared livestock than 61.10% of the control group which has been followed by rearing poultry (54.18% vs. 50.58%). Among other IGAs, making clothes (6.45% vs. 5.34%), grocery and stationary shop (0.87% vs. 0.67%), weaving and tailoring (0.52% vs. 1.34%), tea stall and restaurant (0.35% vs. 0.00%), tobacco products (0.17% vs. 0.00%), other shops (0.17% vs. 0.17%) and other activities (1.22% vs. 1.67%) had been mentioned by ICS and non-ICS respondents consecutively. However, around 2.34% of the non-ICS respondents are found to make handicrafts that are significantly higher than 0.35% of the ICS respondents. On average, the treatment households spent around 99.41 min. in IGAs compared to around 101.02 min. time usage of the control households with the difference being statistically insignificant. Intriguingly, the monthly net earnings of the treatment households were estimated at Tk. 1550.80 which is significantly higher than the estimated monthly net earnings of the control households (i.e. Tk. 1234.27) for the reported IGAs. This further depicts the productive use of the saved time of the women members' from ICS households.

Appendix-III:

Carbon Emission Reduction: Estimation Methodology

Recent literatures have shown evidences that improved cook stove (ICS) interventions could reduce fuel use and pollutant carbon emissions lowering the levels of indoor air pollution (IAP) compared to traditional cook stoves (TCS) (e.g. Mitchell et al. 2019; Thomas et al. 2015). Therefore, in this study, we have estimated indoor air pollution (IAP) status of Improved Cook Stove (ICS) and Traditional Cook Stove (TCS) to illustrate that to what extent the ICS adopters are exposed to IAP in our survey. Our survey results provided us with an ample scope to understand the detailed information on types of cook stove use, cooking time, kitchen characteristics and so on. Based on the information on households' cooking time from BIDS Survey (2018) and secondary information provided by Begum (2017); we have compared two measurement ratios of carbon emission e.g. Particulate Matter (PM) $_{2.5}$ / PM $_{10}$ and Black Carbon (BC) / PM $_{2.5}$ with respect to number of cooking times per day for ICS and TCS adopters. In a study on indoor air pollution levels in households conducted for IDCOL by Begum (2017), estimations regarding PM $_{2.5}$ / PM $_{10}$ and BC / PM $_{2.5}$ in ICS and TCS adopted households have been calculated based on various types of stoves, fuel usage and cooking time per day. Using secondary information from Begum (2017) and primary data information of cooking time per day from BIDS Survey (2018), we have compiled the percentages of ICS and TCS adopters and hence identified the level of carbon emissions (see tables 4.6 and 4.7)) using both indicators of PM $_{2.5}$ / PM $_{10}$ and BC / PM $_{2.5}$.

To elaborate further on this methodology, tables A5 and A6 provide a snapshot of the way information had been summarized with regards to ratios of particulate matters and black carbon based on fuel type, types of ICS and cooking time per day in selected households.

Table A5:

HH No	Fuel Type	PM $_{2.5}$ / PM $_{10}$	BC / PM $_{2.5}$
1	Wood and saw dust	0.70	0.13

Source: Begum (2017).

Table A6:

Source: Begum (2017).

HH No	Type of ICS	Cooking Time/day	Fuel type
1	Double mouth with chimney	3	Wood and saw dust

Based on BIDS Survey (2018), we have compiled the detailed information on the percentages of ICS and TCS adopters and show the extent of IAP levels on the coverage of ICS and TCS adopters in tables 4.6 and 4.7 respectively.