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Determinants and Impact of Solar Irrigation Facility (SIF) Adoption: A Case Study in Northern Bangladesh

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Abstract: Insufficient rainfall in the dry season and scarcity of surface water has resulted in firms' reliance on groundwater for agriculture in the northern part of Bangladesh. Most irrigation systems in the country are diesel or electric, which raises the cost and demand for energy and pollutes the environment. Utilizing the abundant sunshine and disseminating solar-based irrigation systems is expected to be a fittingly rewarding experience for irrigation purposes. Therefore, this study identifies the factors influencing the adoption of solar irrigation facilities (SIFs) and the impacts of their adoption on irrigation cost, return on investment (ROI), and production costs, using survey data collected from 405 rice farmers of Dinajpur district. The study employed three treatment effect estimators, namely inverse probability weighting (IPW), regression adjustment (RA), and inverse probability weighted regression adjustment (IPWRA), to address the potential selection bias issue. The results revealed that farming experience, knowledge, environmental awareness, soil fertility, and irrigation machinery ownership significantly influenced adoption decisions. The treatment effect model result indicated that farmers who adopted this method could minimize irrigation costs by 1.88 to 2.22%, obtain 4.48 to 8.16% higher ROI, and reduce total production cost by 0.06 to 0.98% compared to non-adopters. Our findings suggested that policy interventions targeting scaling up SIFs should consider focusing on government and stakeholders' greater attention on designing more appropriate schemes through experimentation and multiple iterations.

Keywords: solar irrigation; sustainable irrigation; treatment effect estimators; return on investment (ROI); Bangladesh; renewable energy

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1. Introduction

An ecosystems resiliency in sustaining people's livelihoods depends on the interaction between society and the environment. Better resource management and conservation approaches are considered the most potent way to enhance and sustain livelihood conditions [1]. In developing economies where food insecurity is prevalent, effective agricultural practices potentially play a vital role in enabling and sustaining livelihoods [2]. However, studies have indicated that in meeting rising populations' food demand, most developing countries intend to enhance agricultural production capacity and productivity by adopting modern production technologies that promote intensified agriculture practice putting stress on the environment [1,3,4]. This is particularly noticeable in irrigated landscapes where mainly diesel and electric-based irrigation systems are operated. Apart from consuming intensive energy, these systems pollute the environment by emitting carbon dioxide (CO_2) [5]. Furthermore, abiotic constraints such as drought due to increasing temperature and decreasing precipitation negatively impact evapotranspiration demand, surface water availability, food production, nature, and socio-economics of developing countries [6,7].

The increased warming rate has exacerbated aridity, and extreme drought events have increased significantly in various parts of Asia [6,7].

Studies have reported that 77% of the total irrigation in Myanmar is achieved through diesel-powered pumps [8]. Likewise, India utilizes 18% its of total electricity and over 5% of the total diesel for irrigation purposes [9]. Nearly 6 billion kWh of electricity and 3.5 billion liters of diesel are used to operate irrigation pumps in Pakistan [10]. It is worth mentioning that around 1.6 billion people live without electricity in developing countries, and among them, approximately one billion people are from Sub-Saharan Africa and South Asia [11]. Inability to meet energy demand results in higher load shedding, and unreliable energy services affect the pumping requirements for irrigation for small and large farmers [12]. In addition, fossil fuel has particularly adverse effects on the balance of payments in oil-importing countries, and the overall soaring oil prices are considered an unsustainable financial burden to governments [13]. Apart from economic and social costs, fossil fuel usage is associated with severe negative externalities on the environment, adversely affecting economic development in the long term. Studies have revealed that as the greenhouse gas (GHG) emissions from agriculture are much higher in low-income (over 50%) and developing countries (35%), compared to developed countries (12%) [14], it is anticipated that by 2050, there will be a 13% and 15% drop in irrigated wheat and rice yields, respectively, in developing countries [15]. Therefore, the policy manifesto for most developing countries with similar issues has the impetus for adopting reliable, cost-effective, and clean energy irrigation technologies to enhance energy security, prevent local pollution, and increase climate benefits [13,16,17].

Despite being a river realm country, Bangladesh faces a severe water crisis during the dry season [18,19]. Human intervention, variations in climate, inadequate rainfall, and drought have affected surface water recharge and have created a high dependency on groundwater for irrigation, especially in the northern part of Bangladesh [20]. The substantial effect of drought in the northern area over the last two to three decades has adversely impacted the ecosystem and crop productivity [20,21]. Low Lift Pump (LLP), Shallow Tube Well (STW), and Deep Tube Well (DTW) are mainly used for irrigation in the country [22]. These pumps either operate by diesel (i.e., LLP and SWT) or electricity (i.e., DTW). The maximum capacity of DWT is 55 hp, SWT 12.5 hp, and LLP 7.5 hp [17]. Presently, nearly 1.6 million diesel pumps are operating for irrigation purposes [23] and consume at least 1 million tonnes of diesel per year, worth around USD 900 million [24]. Furthermore, diesel fuel is challenging to transport and prone to pollution. It has been reported that a 4HP diesel engine emits about 3744 kg of carbon dioxide every year and is also liable for sound pollution during operation [17]. On the other hand, around 3.20 lakh pumps run on electricity to irrigate crops on a total of 5.45 million hectares in the dry season, consuming approximately 2000 megawatts (MW) of electricity for irrigating rice fields [24]. According to recent estimates, irrigation consumes about 4.58% of the total electricity generated in the nation [25], and the electricity demand in the 2022 upcoming irrigation season is expected to rise from 14,097 MW to 15,500 MW [26]. Even though electric irrigation is less harmful to the environment, the country suffers from energy deficiencies [27]. Frequent power outages, voltage fluctuations, and increasing tariffs impact farmers' earnings and hamper production. The power outage issue also hinders farmers' nightlife and forces them to operate pumps at night when grid electricity demand is lower [28]. Likewise, diesel-driven pumps increase farmers' operation costs and are prone to service gaps due to an insufficient fuel supply and technical defects [5]. In addition, both systems' limited area coverage ability in the peak season negatively affects crop productivity [29].

In the face of these challenges, concerns have been raised around tackling human activities' negative impact of exploiting natural resources while protecting the ecosystem and achieving agricultural sustainability in Bangladesh. Therefore, like many other developing countries, Bangladesh has also embraced the sustainable development goals that, apart from emphasizing ameliorating critical issues, also highlights the importance of understanding complex and evolutionary links between ecosystems and human societies, the changing environmental paradigms, and advocates for the uptake of green technology and improved farm management strategies to achieve sustainability for the present and future generations [3]. Thus, being primarily an agrarian economy, the country has prioritized enhancing water supply to boost agriculture productivity and food security by implementing robust and well-managed irrigation systems. In continuation of promoting affordable, reliable, and environmentally sustainable technologies, the government initiated a solar energy-based irrigation project (SIP) in 2010 with a target to install 50,000 solar irrigation pumps by 2025 in order to minimize the energy crisis and reduce depletion of fossil fuel reserves while ensuring sustainable water management in agriculture sectors [30,31].

Solar energy is known as one of the most secure and low-cost sources of electricity, and in a country such as Bangladesh with abundant sunshine for most of the year, sourcing energy from the sun rays should be a fittingly beneficial experience for irrigation purposes. Since the need for water is the highest on hot sunny days, this technology is an obvious choice [32]. Studies have revealed that solar irrigation technology is more economical than the diesel system and can cover larger areas and provide water to more farmers at the same time during peak season compared to diesel and electric facilities, due to higher capacity, the option of buried pipelines, and operational advantage of the number of risers [29]. Likewise, replacing diesel and electric irrigation systems with solar is expected to reduce 17,261 tons of carbon dioxide emissions annually [25] and to enhance the present and future energy mix by replacing 10% of the conventional energy [33]. So far, 2223 solar irrigation pumps are operational with an installed capacity of around 45.076 megawatts per hour [34], providing water on more than 27,024.91 hectares of land for rice cultivation [30].

However, despite the significant potential, promotion activities for SIF have been slow [33,35]. Even though there have been extensive studies on analyzing feasibility [17], the technical prospects [19], techno-economics and challenges [36], or financial [37] aspects, only two studies [33,38] have focused on determinants and impact evaluation. Compared to other studies, this study contributes to the literature in several ways.

Firstly, the study attempts to unravel factors that have influenced farmers' adoption and non-adoption behavior. Secondly, this study assessed the impact of adoption on irrigation cost, return on investment (ROI), and production costs. Other studies have focused on crop yields or farm profit without considering the ROI [33,38]. As the return on investment variable considers the gross revenue of farm production and the production costs, it can better reflect the efficiency of farm performance [39,40].

Finally, the empirical approach of this study also differs from previous studies as we choose treatment effect models to address the selection bias issue, whereas previous solar irrigation studies have not taken the selection bias issue into account [33,38,41–44].

2. Materials and Methods

2.1. Study Area, Sampling Procedure, and Data Source

This study focuses on the drought-prone area of the northern region of Bangladesh that receives merely 372 mm of rain from November to May, compared to 546 mm during the same time period in the whole country. The average annual rainfall is estimated to be 21.83% lower than the country's average annual rainfall. Inadequate rainfall and limited surface water have created high dependence on groundwater for cultivation and irrigation in these areas, leading to significant declines in groundwater levels [20,45].

For this study, multistage sampling techniques were employed. At first, the Dinajpur district was selected (Figure 1) for several reasons. Dinajpur is the largest district among all sixteen districts situated in the northern part, and according to the international 'Köppen climate classification,' the district has a tropical wet-dry climate. The annual average temperature is 25 °C. The average precipitation from November to March is below 20 mm, April and October below 100 mm, and in the remaining five months over 200 mm [46]. Due to the low precipitation rate, the district is considered one of the top drought-prone areas of Bangladesh [21,45,47], where the food insecurity and poverty rate are high [48]. This district is also one of the top districts where more solar irrigation pumps are installed [34]. In the second stage, a simple random sampling method was used to select 3 out of 13 sub-districts from the Dinajpur district. The randomly chosen three sub-districts were Birganj, Khanshama, and Kaharol. The combined population of these three sub-districts is 643,431 [49]. We then used Krejcie and Morgans' [50] table to determine the optimal sample size. A sample of at least 384 farmers was determined based on our population size. However, to minimize unexpected errors that may arise due to respondents' non or partial response, we felt collecting additional 5% samples. Hence, to sample an equal number of respondents, we finally collected 405 samples comprising 135 respondent farmers from each sub-district.

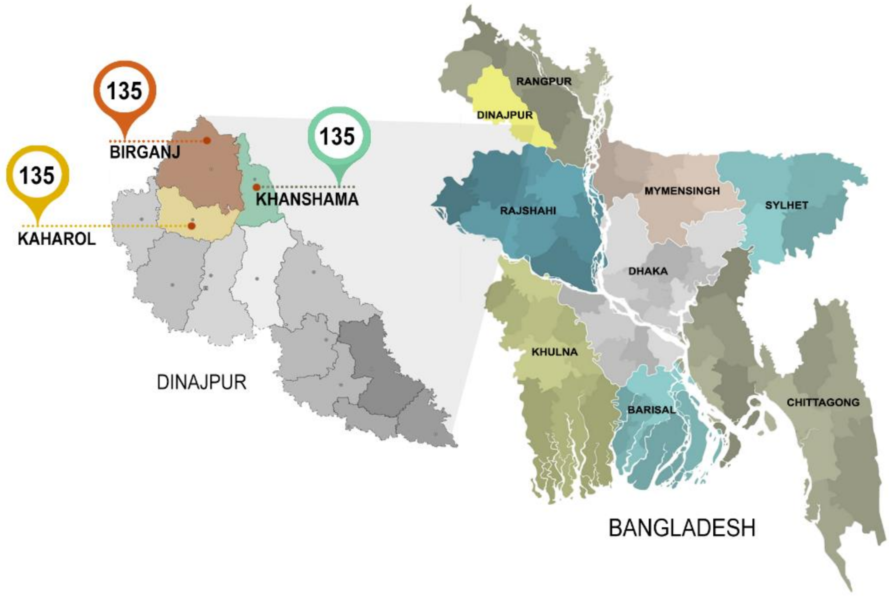

Figure 1. Overview of the study region within Bangladesh and the study areas in Dinajpur district.

Face-to-face interviews were conducted between February and April 2021 to collect the necessary data using a semi-structured interview schedule. The Boro season (December to June) was chosen, since the greatest amount of rice is produced in this season [51], and irrigation demand is very high. The interview schedule was translated into the local language for implementation and was pretested before finalization. The interviewed respondents were rice-producing farmers. Our interview included farmers' demographic and socioeconomic characteristics service and infrastructure-related questions. We also asked farmers about their adoption or non-adoption behavior, knowledge sources, fee opinion, environmental consciousness, and agro-ecology-related questions.

2.2. Analytical Technique

2.2.1. Theoretical Framework

For this study, we adopted the random utility theory developed by McFadden in 1974 [52], which is consistent with Lancaster's economic theory of value and the neoclassical view that posit that individuals derive utility from the features of goods or services rather than directly from the good or service as a whole [53,54]. The random utility approach links the deterministic model with a statistical model of human acts [55] and allows elicit preferences for complex multidimensional goods or services, from which models of preferences can be estimated. The assumption is that individuals would choose alternatives that maximize their utility [56]. Following this theory, the utility that an individual n gains from alternative j, identified as U_{nj}, is expressed as a function of attributes (X):

$$U_{nj} = \beta_n X_{nj} + \varepsilon_{nj} \tag{1}$$

where U_{nj} is the net gain from adoption, β_{n} is the systematic or measurable component that is a function of observable attributes X_{nj} and a random component capturing variations in preferences in the population due to unobservable stochastic error term ε_{nj}.

2.2.2. Empirical Approach

Factors Influencing Adoption

Most of the studies that have investigated farmers' adoption decisions regarding a single technology have used binary logit or probit models as these methods are considered the most suitable approaches that can provide more comprehensive details of both adopters and non-adopters [57–59]. For this specific study, we used the logit model to investigate factors influencing the acceptance of solar irrigation facilities because the adoption process itself is logistic (a farmer who accepted the practice is, considered as an adopter and assigned a score of 1, otherwise assigned to 0) and is consistent with the literature on adoption [60,61]. Furthermore, the Logit model is preferred over the probit model in this paper for its mathematical simplicity and ease of use [62] while also being common across similar studies [60,63,64]. The empirical model for the logit model estimation is specified as follows:

$$Z_i = log\frac{p_i}{1-p_i} = \alpha + \beta X_i + \varepsilon_{ij} \tag{2}$$

where, X_i is the explanatory variables and $log\frac{p_i}{1-p_i}$ is the logarithm of odds of farm households' decision to adopt solar irrigation facility $(Z_i = 1)$ versus not adopt $(Z_i = 0)$.

Impact Assessment

Prior studies [57,65] have suggested that in the absence of prior intervention data, the impact of technology adoption can be assessed through instrumental variable-based regression or treatment effect models. However, this study employed treatment effect models to estimate the impacts due to the lack of valid instruments, because choosing an inappropriate instrumental variable may raise the omitted variable or bias issue [66].

The present study used three different treatment effect models: inverse probability weighting (IPW), regression adjustment (RA), and inverse probability weighted regression adjustment (IPWRA). The IPW estimator in calculating the average value of the outcome variable uses the inverse of the propensity score as weights [67,68], while the RA model uses the differences of the averages of treatment-specific predicted outcomes [69]. On the other hand, the IPWRA model with double-robust property uses probability weights in obtaining outcome regression parameters to account for the missing-data problem. The adjusted outcome-regression parameters are employed to calculate averages of treatment-level predicted outcomes. The contrasts of these averages provide assessments of the treatment effects [69,70]. The IPWRA allows the outcome and the treatment model to account for misspecification [71].

To examine the impact of solar irrigation, we estimate the average treatment effect on treated (ATT). The ATT estimates the expected causal effect of the treatment for individuals in the treatment group. The IPW is assessed through weighting the observations based on the inverse probability of being treated, and the probability of being treated can be expressed as [72]:

$$p(X) = \Pr(T_i = 1|X) = F\{h(X)\} = E(T_i|X) \tag{3}$$

In this equation, $'X'$ is the vector of covariates and $F\,\{.\}$ is a cumulative distribution function. This model is used to create a synthetic sample in which the distribution of measured baseline covariates is independent of treatment assignment. However, in defining weights, we first follow Manda et al.'s, [73] study where inverse weights are ascribed to

1 for the treated and $\frac{\overline{p}(x)}{1-\overline{p}(x)}$ for the non-treated, and then follow Hirano and Imbens [74] study. Hence, the ATT for IPW is defined in a combined way as:

$$w_i = T_i + (1 - T_i)\frac{\overline{p}(x)}{1 - \overline{p}(x)} \tag{4}$$

In this equation, $\overline{p}(x)$ exemplifies the estimated propensity scores.

On the other hand, the RA estimator through the linear regression model obtains the treatment effects [73]. The ATT for the RA model can be expressed as [70]:

$$ATT_{RA} = n_A^{-1} \sum_{i=1}^{n} T_i[r_A(X, \delta_A) - r_N(X, \delta_N)] \tag{5}$$

where, n_A denotes number of adopters $r_A(.)$ and $r_N(.)$ is the proposed regression model for the adopters and non-adopters (N) based on observed covariates X and parameters $\delta_i = (\alpha_i,\ \beta_i),\ (j = A,\ N)$. Finally, combining the regression adjustment Equation (5) with weighting Equation (4), ATT for the IPWRA estimator can be expressed as:

$$ATT_{IPWRA} = n_A^{-1} \sum_{i=1}^{n} T_i[r_A^*(X, \delta_A^*) - r_N^*(X, \delta_N^*)] \tag{6}$$

where $\delta_A^* = \left(\alpha_A^*, \beta_A^*\right)$ and $\delta_N^* = \left(\alpha_N^*, \beta_N^*\right)$ are the estimated inverse probability-weighted parameters obtained from the weighted regression methods for adopters and non-adopters of solar irrigation facilities, respectively:

$$\min_{\alpha_A^*, \beta_A^*} \sum_{i=i}^{N} w_i(y_i - \alpha_A^* - X\beta_A^*)^2 / \hat{p}(X, \hat{\gamma}) \tag{7}$$

$$\min_{\alpha_N^*, \beta_N^*} \sum_{i=i}^{N} (1 - w_i)\ (y_i - \alpha_N^* - X\beta_N^*)^2 / (1 - \hat{p})\ (X, \hat{\gamma}) \tag{8}$$

The IPWRA estimator, compared with RA, uses weighted regression coefficients in calculating ATT, where weights are the estimated inverse probabilities of treatment [69]. Hence, IPWRA is considered a double robust estimator [40]. It is essential to mention that the IPWRA method relies on two assumptions: conditional independence or unconfoundedness and overlap condition or common support assumptions. The first assumption states that once we have controlled all the observable covariates, the potential outcomes are independent of the treatment status. The second assumption is that conditioning on a set of covariates increases the probability of each individual being treated or untreated [73,75].

2.3. Measurement of Key Variables

The outcome variables for this study are irrigation cost, ROI, and production costs. Irrigation cost is measured in BDT (BDT is Bangladeshi currency, USD 1 = BDT 86 approximately). The ROI is the ratio of net earnings to the production costs, defined in accordance with previous studies [39,40]. The production costs include seeds, fertilizer, pesticides, irrigation, and other input costs, measured at BDT/50 decimal. The treatment variable for this study is a dummy variable, which is equivalent to 1 if a farmer has adopted the solar irrigation facility and 0 otherwise. The explanatory variables chosen for this study were based on the existing literature and prior expectation [59,76–99]. The description of the variables is presented in Table 1.

Table 1. Variables used in different models.

Variables	Measurement Unit	Description
Outcome Variables		
Irrigation cost	BDT/50 Decimal	Total costs of Irrigation
ROI	Ratio of net returns to the production costs	Return on investment
Production costs	BDT/50 Decimal	Total costs of production
Treatment Variable		
Adoption	Dummy variable	0 = Farmer have not adopted SIF, 1 = Farmers have adopted SIF
Explanatory Variables		
Age	Dummy variable	1 = Young aged farmers, if age is ≤30 years, 2 = Old aged farmers, if age is >30 years
Education	Dummy variable	0 = Illiterate (can only sign the name), 1 = Literate (can read, write and sign)
Land Ownership	Dummy variable	0 = Farmer does not have land ownership rights 1 = Farmer has full land ownership rights,
Land Typology	Dummy variable	0 = Low land, 1 = Highland
Farming Experience	Years	Respondents farming experience in years
Household Size	Dummy variable	1 = Respondents household number is ≤4 persons, 2 = Respondents household number is >4 persons
Family Labor	Number	Number of household labor
Farm Size	Decimal	Respondents farm size in decimal
Knowledge of SIF	Dummy variable	0 = Farmer possess partial knowledge of SIF, 1 = Farmer possess proper knowledge of SIF
Fee Opinion	Dummy variable	0 = Respondent thinks fee is not high, 1 = Respondent thinks fee is high
Soil Fertility Perception	Dummy variable	2 = Respondent perceives their farmland as fertile, 1 = Respondent perceives their farmland as infertile
Cash Availability	Dummy variable	1 = Respondent had cash constraints during the cropping season, 2 = Respondent had no cash constraints during the cropping season
Soil Water Retention condition	Dummy variable	1 = If the soil can hold water long, 2 = If the soil unable to hold water for long
Irrigation machine ownership	Dummy variable	0 = Farmer do not own diesel or electric pump, 1 = Farmer own diesel or electric pump
Close Acquaintances adoption	Dummy variable	1 = Respondents close acquaintances have adopted SIF, 0 = Respondents close acquaintances have not adopted SIF
Environment Awareness	Dummy variable	1 = The farmer knows SIFs adoption aids the environment, 0 = The farmer does not know SIFs adoption aids the environment

3. Result and Discussion

3.1. Basic Household Characteristics of the Survey Respondents

Table 2 presents selected characteristics differences between adopters and non-adopters. The mean difference suggested significant differences between adopters and non-adopters in terms of selected household characteristics.

Table 2. Characteristics of the adopters and non-adopters.

Characteristics	Adopters	Non-Adopters	Mean Difference	$\chi 2$ Value/*t*-Value
Age	1.878	1.885	−0.007	$\chi 2$ = 0.047
Education	0.873	0.845	0.028	$\chi 2$ = 0.664
Land Ownership	0.941	0.950	−0.009	$\chi 2$ = 0.144
Land Typology	0.239	0.165	0.074	$\chi 2$ = 3.435
Farming Experience	26.927	29.105	−2.178 **	*t* = 2.282
Household Size	1.439	1.475	−0.036	$\chi 2$ = 0.528
Family Labor	1.140	1.137	0.003	*t* = 0.070
Farm Size	93.234	94.265	−1.031	*t* = 0.127
Knowledge of SIF	0.693	0.385	0.308 ***	$\chi 2$ = 38.591
Fee Opinion	0.307	0.460	−0.153 ***	$\chi 2$ = 9.990
Soil Fertility perception	1.341	1.300	0.041	$\chi 2$ = 0.799
Cash Availability	1.590	1.570	0.020	$\chi 2$ = 0.170
Soil Water Retention	1.351	1.295	0.056	$\chi 2$ = 1.462
Irrigation Machine Ownership	0.434	0.485	−0.051	$\chi 2$ = 1.054
Close Acquaintances Adoption	0.683	0.400	0.283	$\chi 2$ = 32.658
Environment Awareness	0.659	0.550	0.109 **	$\chi 2$ = 4.990

Note: ** and *** denote significance of mean difference at 5% and 1% level respectively.

The $\chi 2$ and *t*-test value denotes prevailing significant differences between adopters and non-adopters concerning farming experience ($p < 0.05$), Knowledge of SIF ($p < 0.10$), Environment Awareness ($p < 0.05$), and Fee Opinion ($p < 0.10$), which also indicates that the two groups are not directly comparable, and justifies the use of the treatment effect model.

3.2. Factors Affecting Adoption

The factors influencing farm households' adoption of solar irrigation facilities were analyzed using binary logistic regression, and the results are presented below (Table 3). Since the coefficient result only expresses the direction of change and not the probability or magnitude of change, the marginal effects were also analyzed and included in the table. The calculated VIF value for all the variables is well-below the conventional threshold of 10, indicating no severe collinearity [100].

Table 3. Factors affecting the adoption of a solar irrigation facility.

Variables	Coefficient	Marginal Effects (dy/dx)	Standard Error	VIF
Age	0.309	0.061	0.081	1.43
Education	0.253	0.050	0.065	1.06
Land Ownership	−0.083	−0.017	0.089	1.07
Land Typology	0.500	0.099	0.072	1.78
Farming Experience	−0.031 **	−0.006	0.003	1.46
Household Size	−0.364	−0.072	0.046	1.05
Family Labor	0.063	0.013	0.054	1.13
Farm Size	−0.001	−0.000	0.000	1.45
Knowledge of SIF	1.267 ***	0.251	0.041	1.12
Fee Opinion	−0.411 *	−0.082	0.047	1.08
Soil Fertility perception	0.768 ***	0.152	0.057	1.39
Cash Availability	0.550 **	0.109	0.055	1.51
Soil Water Retention	0.168	0.033	0.066	1.90
Irrigation Machine Ownership	−0.566 **	−0.112	0.049	1.16
Close Acquaintances Adoption	0.997 ***	0.198	0.042	1.07
Environment Awareness	0.442 *	0.088	0.045	1.04

Number of observations = 405; LR chi2 (16) = 78.06; Prob > chi2 = 0.000; Log likelihood = −235.396; Pseudo R^2 = 0.1614; Note: *** represents 1% ($p < 0.01$), ** 5% ($p < 0.05$) and * 10% ($p < 0.1$) significance level.

Among the variables shown above (Table 3), farmers' age was found to be insignificant to adoption, which is similar to other studies conducted in Nepal and Niger [77,101]. This result indicates further study on more heterogeneous farmers' age groups, as there seem to be complementarities between the human capital of younger and older farmers. For instance, younger generations' higher engagement with ICT connects them across vast geopolitical barriers and helps them gather information about new technologies. In contrast, the older generation has more experience and better knowledge of the intra-firm structure and the operating process.

The insignificant association between farmers' literacy level and decision to accept SIF may be due to most rural families' decision-making norm that usually involves the whole family in the decision process. So, if most family members lack the knowledge to understand the benefits of the solar irrigation system, the family may not decide to adopt the technology. This result is consistent with other adoption studies conducted in Thailand and China [78,102].

Land ownership does not influence the adoption process, which is anticipated as being due to the knowledge deficiency of the landowner farmers about the long-term productivity advantage of uptaking SIF [79,103]. Likewise, land typology also exhibits non-statistically significant effects on the probability of SIF acquisition. A probable explanation for this may be that the adoption of modern irrigation technologies more likely depends on the land's quality and water-holding capacity. The result is in line with previous studies [82,104].

Farmers' farming experience was statistically significant ($p < 0.05$) but negatively correlated to adoption, indicating that more experienced farmers are less likely to adopt solar irrigation facilities. The marginal effect depicts that a unit increase in farmers' farming experience decreases the probability of solar irrigation acceptance by 0.6%. Similar discoveries indicated that younger farmers are more vigorous in trying out newer innovations, while farmers with more experience are more likely to stick with the conventional methods they are familiar with [59].

The non-impact of household size on SIF acceptance could be due to the consumption need of a larger household which tends to compete with the investment of irrigation cost. This finding was in harmony with the observation of other studies that reported no significant influence of household size on technology adoption [85,105].

Family labor availability was found not to be associated with the adoption decision. This result may indicate that the ratio of the household laborer to the hired worker is smaller in our study area [86]. The result is meaningful because, out of 405 respondents, only 13% of the adopted households have reported having an extra family member who helps them in the field. However, this does not indicate the availability of household fixed labor because most rural youths, instead of engaging in agriculture, prefer working in public or private organizations due to social recognition [106]. As a result, even they go to the field, they do not work full-time, and the household credit constraints issue does not become resolved. For hard work, the family still needs to hire paid labor.

The probable non-significant association [105] between farm size and SIF adoption could be due to either adaptation being plot-specific, meaning that not the size of the farm but other characteristics of the farm dictates the need for a specific adaptation method [88], or that large farms are often associated with lower management and information costs per unit of output [79]. Thus, future research that accounts for farm characteristics could reveal more information about factors dictating adaptation to climate change at the farm or plot level.

As expected, farmers with proper knowledge of solar irrigation facilities were a significant determinant ($p < 0.01$). The marginal effect indicated that the tendency of adopting SIF increases to 25.1% if a farmer possesses proper knowledge of the facility. Our result confirmed Bairagi et al.'s [90] and Kabunga et al.'s [107] studies.

Fee opinion is significant ($p < 0.01$) but negatively related to adoption. Results on marginal effects show that a unit increase in fees will decrease the chance of adoption rate by 8.2%, ceteris paribus. Although this result is consistent with another study [59], it may probably indicate farmers' credit constraint issues, a lack of understanding of the long-run benefit of these facilities, or the lack of adequate publicity by government and service providers [59,76].

Soil fertility was positively and significantly associated with solar irrigation adoption. The marginal effect indicated that the adoption probability of farmers with a fertile plot is 15.2% higher than those cultivated in the less fertile plot. This result is consistent with Kassie et al.'s [91], and Ndiritu et al.'s [108] studies that revealed that soil fertility is associated with adopting different sustainable intensification practices (SIP).

Cash availability was positive and significantly associated with solar irrigation adoption. The marginal effect indicated that farmers' SIF accepting probability increases to 10.9% if the farmer faces no cash constraints during the cropping season. This result is consistent with other studies that pointed out that access to credit can ease farmers' liquidity constraints, alleviate households' risk-bearing conditions, and thus increase the adoption chances of new technology [92,93].

Soil water retention was insignificant and not correlated to adoption. The result may be due to farmers' soil-moisture-detection process through above-ground plants instead of measuring in-depth soil water-retention conditions, or their knowledge deficiency regarding adopting innovative irrigation technology that can assure efficient water supply [94,95].

Farmers' machinery ownership was negative but significantly ($p < 0.05$) associated with SIF acceptance. The marginal effect indicated that farmers' solar irrigation adoption probability decreases to 11.92% if the farmer owns any irrigation system.

Close acquaintances' adoption of SIF significantly ($p < 0.01$) influenced the adoption decision of respondents. The marginal effect indicated that farmers' solar irrigation adoption probability increases to 19.7% if the close acquaintances also adopt. The result matches Mendola's [97] and Krisnan and Patnams' [109] studies that has stated that close acquaintances' acceptance of a new technology positively affects farmers' decision-making process to accept that technology.

Environmental awareness was found to be positive and significantly associated with the acceptance of SIF. The marginal effect indicates that the probability of adoption increases by 8.8% if farmers know that acceptance will aid in carbon footprint reduction. This result matches our expectations and with previous research outcomes [99].

3.3. Adoption Impact

Before finalizing the models, we have checked the balancing property and overlap assumption of the models. The insignificant value of X2 ($\chi 2 = 7.99567$, $Prob > chi2 = 0.9666$) indicates that covariates are balanced. Likewise, the balancing summary estimates outlined in Table 4 report the model-adjusted difference in means and ratio of variances between the treated and untreated for each covariate. The result indicates that standardized differences and variance ratio of all the variables were close to zero and one, respectively. This result confirms that balancing property is satisfied.

Further, in testing the overlap assumption, we used overlap plots (Figure 2). The graphical diagnostic result indicated that all the estimated densities had most of their respective masses in regions in which they overlap each other.

The adoption impact results in Table 5 show that the adoption of solar irrigation has a significant impact on irrigation cost, ROI, and production cost. Specifically, farmers who adopted solar irrigation facilities could minimize irrigation cost by on average 1.88 to 2.22%, obtain 4.48 to 8.16% higher ROI, and reduce production cost by 0.06 to 0.98% compared to non-adopters. Our findings align with previous studies that document the significant impact of technology adoption on irrigation cost, ROI, and production cost [40,110,111].

Table 4. Covariates balancing summary.

Variables	Standardized Differences		Variances Ratio	
	Raw	Weighted	Raw	Weighted
Age	−0.021	0.027	1.052	0.938
Education	0.081	0.011	0.845	0.977
Land Ownership	−0.038	0.008	1.160	0.965
Land Typology	0.185	0.021	1.320	1.034
Farming Experience	−0.227	−0.038	0.823	0.871
Household Size	−0.072	0.004	0.987	1.000
Family Labor	−0.007	0.021	1.018	1.186
Farm Size	−0.013	−0.033	1.067	1.051
Knowledge of SIF	0.647	0.023	0.899	0.997
Fee Opinion	−0.317	−0.045	0.857	0.978
Soil Fertility perception	0.089	−0.017	1.071	0.987
Cash Availability	0.041	0.041	0.987	0.987
Soil Water Retention	0.120	0.036	1.095	1.029
Irrigation Machine Ownership	−0.102	−0.016	0.983	0.997
Close Acquaintances Adoption	0.591	0.035	0.902	0.997
Environment Awareness	0.223	0.033	0.908	0.984

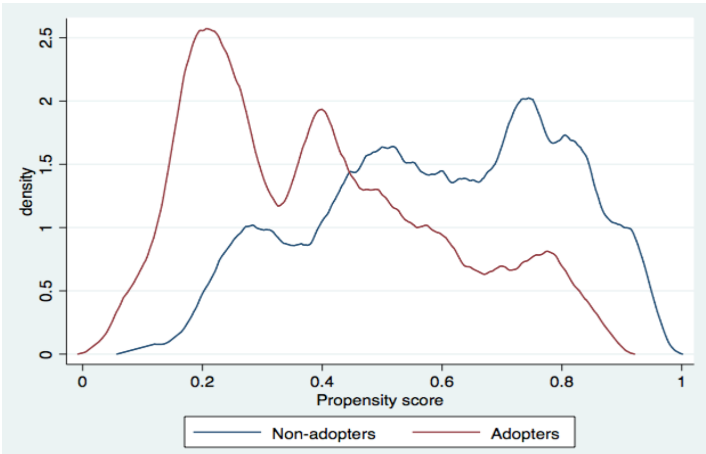

Figure 2. Test of overlap assumption.

Table 5. Average treatment effects of solar irrigation adoption on outcome variables.

Outcome Variables	IPW			RA			IPWRA		
	ATT	Robust S. E.	% ↓/↑ than POM	ATT	Robust S. E.	% ↓/↑ than POM	ATT	RobustStd. Err.	% ↓/↑ than POM
Irrigation cost	−0.17 ***	0.042	1.90 ↓	−0.16 ***	0.029	1.88 ↓	−0.20 ***	0.037	2.22 ↓
ROI	0.08 *	0.044	5.49 ↑	0.12 ***	0.042	8.16 ↑	0.08 *	0.042	4.48 ↑
Production cost	−0.06	0.043	0.57 ↓	−0.06 **	0.028	0.06 ↓	−0.10 ***	0.037	0.98 ↓

Note: ATT refers to average treatment effects on the treated; S.E. represents Standard Error; ↓ and ↑ Indicates lower and higher, respectively; POM denotes Potential Outcome Mean; ***, ** and * indicates significance at 1%, 5% and 10% levels, respectively.

3.4. Service Quality Satisfaction Level of the Adopters and Non-Adopters

We wanted to know the adopters' opinion and non-adopters' perception of service quality. Our survey result outlined in Table 6 revealed that 30.37% of adopters reported overall service quality satisfaction. However, among total respondents, 34.41% (41 adapters and 100 non-adopters) stated dissatisfaction with the site operators' behavior and performance. Likewise, 15.12% of adopters were unhappy with the solar irrigation systems' performance as the system fails to withdraw and supply adequate water in the cloudy period, and to mitigate the issue, diesel pumps need reinstating. Similarly, 4.88% of adopters expressed disappointment with service providers' support issues. Further, among half of the non-adopters, 21% expressed concern about the ability of the system performance, while the rest, 29%, could not rely on either operator or the service providers.

Table 6. Sentiment of the farmers towards service of the providers.

Thoughts of the Farmers	Adopter	Non-Adopter	Total
Satisfied	123	0	123
Operator issue	41	100	141
Water issue in cloudy weather	31	42	73
Service provider support delay	10	0	10
Failed to convince me	0	58	58

Source: Field Survey Data, 2021.

Since most adopters and non-adopters have complained against site operators, we thought it would be worth knowing what counterparts think. Among 30 site operators we interviewed, 63% have stated that not allowing adopted farmers to pay less is the main reason for their dissatisfaction. Further, 23.33% recounted that it becomes difficult to satisfy everyone when the water requirement is high in the dry season. The rest, 13.33%, indicated that occasional delay in repairing work is associated with dissatisfaction.

On the other hand, 60% of site operators specify that diffusion of solar irrigation facilities hampers diesel and electric pump owners' business, making them unhappy. The remaining 40% of operators, think that non-adopters who cannot access solar irrigation systems due to capacity issues and those with personal issues complained against them.

4. Conclusions and Recommendations

In this study, determinants of farmers' adoption of SIF and its impacts at the farm-level were measured by employing a set of treatment effect models. The results showed that SIF knowledge, soil fertility perception, cash availability, close acquaintances adoption, and environment awareness largely influence farmers' adoption decisions. In contrast, farming experience, fee opinion, and ownership of irrigation machines were found to be negatively associated with adoption. Furthermore, the results of the ATT estimates exhibited a positive impact of solar irrigation adoption on irrigation cost, ROI, and production cost. Since this study information gathered from 405 interviewed farmers of three districts of Bangladesh, it does not rule out the possibility of generalizing the results to other regions with similar climatic and socio-economic conditions.

The findings of this study have practical policy implications. Firstly, the positive impacts of SIF adoption on irrigation cost, ROI, and production cost highlight the need for government and stakeholders' greater concentration on designing more appropriate schemes through experimentation and multiple iterations. However, the process needs to be nimble enough to respond to new knowledge gained over time, and the schemes must be attractive enough to create strong demand from farmers.

Secondly, our respondents' complaints about SIF performance raise questions on solar panels' efficiency. As our field survey took place in 2021, several farmers from various sites had reported that the present water discharge amount of these systems compared to 2015 (when these systems were first installed) had declined. Undoubtedly, the efficiency will decline gradually, and replacement is required after a particular time. However, the project report states that the panels expected life is ten years, but the farmers are experiencing significant efficiency issue differences within five years. Therefore, emphasis should be given on regular monitoring of panel efficiency and policy support to upgrade the low-efficiency solar panels with high-efficiency panels regularly. For instance, at present, we should consider substituting polycrystalline solar panels with monocrystalline or $CuBi_2O_4$ cell-based thin-film solar cells to avoid reinstating diesel irrigation systems in peak time because reinstating raises conflicts with the government's strategy of minimizing carbon footprint initiatives and hindering development initiatives. However, financial incentives are essential to bear the additional cost of replacing other types of solar panels, and quick scale-up of SIF requires the fee to be at least the same or lower than other technologies. Hence, for the sake of the sustainability of this sector, policymakers should consider extending tenure and grace time to at least 20 years (it is currently ten years) and facilitating lower interest rates than the banks are offering for general projects.

Thirdly, our results suggest the importance of innovative managerial implications that focus on field demonstration programs and campaigns to promote benefits and environmental awareness rather than merely promoting adoption. Likewise, we urge further study on heterogeneous age groups' perception of SIF and their awareness of environmental severity for a better understanding of farmers' risk management behavior.

SIFs expansion can reduce the conventional energy demand for agriculture, as unused power is promptly fed back into the power grid. The government should speed up the grid-tied solar system expansion process to utilize unused electricity for fertilizer production. The self-reliance of the fertilizer sector will help retain food autarky and economic growth. Likewise, the future electricity production cost is anticipated to rise due to coal and furnace oil supply-chain disruption. Hence, sustainable SIF deployment can play a vital role in conserving conventional energy sources and resolving future crisis issues.

It should be kept in mind that sponsors' sustainability in generating satisfactory revenue depends on appropriate site selection. Therefore, while selecting the site, sponsors should extensively study farmers' seasonal crop choosing patterns, future pipeline expansion plans, soil slope, potential customers' attitudes and perceptions towards SIF, and the market price of water-intensive crops. Because once the installation is completed, shifting would not be cost-effective. Anecdotal evidence from several service providers and site operators suggested that when water-intensive crops' market prices decline, farmers' crop cultivation patterns also change, which negatively impacts sponsors' earnings most of the time.

Further, initiatives should protect solar sites from vested groups who do not advocate for SIF expansion. At the same time, policies must consider hedging against the potential production risk by introducing an insurance scheme or introducing safety nets to cover against such a downside risk. In addition, focus should be given on region-specific installation of small, medium, and high-capacity SIFs while restricting the installation of mixed types in the same region to avoid internal conflicts between service providers.

Despite the fact that this study generates some useful information, it has some certain drawbacks. Therefore, future research endeavors should consider larger sample sizes and include other areas of Bangladesh. Likewise, studies should explore the impact of adopting SIF on the environment and what percent of higher ROI and cost reduction can attract farmers to become interested in SIF.

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References

1. Agula, C.; Akudugu, M.A.; Mabe, F.N.; Dittoh, S. Promoting Ecosystem-Friendly Irrigation Farm Management Practices for Sustainable Livelihoods in Africa: The Ghanaian Experience. *Agric. Food Econ. Vol.* **2018**, *6*, 21. [CrossRef]
2. Tang, Q.; Bennett, S.J.; Xu, Y.; Li, Y. Agricultural Practices and Sustainable Livelihoods: Rural Transformation within the Loess Plateau, China. *Appl. Geogr.* **2013**, *41*, 15–23. [CrossRef]
3. Es'haghi, S.R.; Rezaei, A.; Karimi, H.; Ataei, P. Institutional Analysis of Organizations Active in the Restoration of Lake Urmia: The Application of the Social Network Analysis Approach. *Hydrol. Sci. J.* **2022**, *67*, 14. [CrossRef]
4. Lavlu, M. Agricultural Productivity and Food Security in the Developing World. *Bangladesh J. Agric. Econ.* **2012**, *35*, 53–69.
5. Energypedia. Powering Agriculture: Irrigation. Available online: https://energypedia.info/wiki/Powering_Agriculture:_Irrigation (accessed on 10 May 2021).
6. Sun, C.; Zhu, L.; Liu, Y.; Hao, Z.; Zhang, J. Changes in the Drought Condition over Northern East Asia and the Connections with Extreme Temperature and Precipitation Indices. *Glob. Planet. Change* **2021**, *207*, 103645. [CrossRef]
7. Venkatappa, M.; Sasaki, N.; Han, P.; Abe, I. Impacts of Droughts and Floods on Croplands and Crop Production in Southeast Asia—An Application of Google Earth Engine. *Sci. Total Environ.* **2021**, *795*, 148829. [CrossRef] [PubMed]
8. Frenken, K. *Irrigation in Southern and Eastern Asia in Figures AQUASTAT Survey—2011; FAO Water Reports 37*; Food and Agriculture Organization of the United Nations: Rome, Italia, 2012.
9. IRENA. *Solar Pumping for Irrigation: Improving Livelihoods and Sustainability; IRENA POLICY BRIEF*; The International Renewable Energy Agency: Abu Dhabi, Emirates, 2016; p. 32.
10. Qureshi, A.S. Reducing carbon emissions through improved irrigation management: A case study from Pakistan. *Irrig. Drain.* **2014**, *63*, 132–138. [CrossRef]
11. The World Bank. Access to Energy Is at the Heart of Development. Available online: https://www.worldbank.org/en/news/feature/2018/04/18/access-energy-sustainable-development-goal-7 (accessed on 13 December 2018).
12. Hoque, N.; Roy, A.; Beg, M.R.A.; Das, B.K. Techno-Economic Evaluation of Solar Irrigation Plants Installed in Bangladesh. *Int. J. Renew. Energy. Dev.* **2016**, *5*, 73–78. [CrossRef]
13. Rentschler, J.; Bazilian, M. Reforming Fossil Fuel Subsidies: Drivers, Barriers and the State of Progress. *Clim. Policy* **2016**, *17*, 891–914. [CrossRef]
14. Fellmann, T.; Witzke, P.; Weiss, F.; Doorslaer, B.V.; Drabik, D.; Huck., I.; Salputra, G.; Jansson, T.; Leip, A. Major Challenges of Integrating Agriculture into Climate Change Mitigation Policy Frameworks. *Mitig. Adapt. Strateg. Glob. Chang.* **2018**, *23*, 451–468. [CrossRef] [PubMed]
15. Gilbert, N. One-third of Our Greenhouse Gas Emissions Come from Agriculture. Available online: https://www.nature.com/news/one-third-of-our-greenhouse-gas-emissions-come-from-agriculture-1.11708 (accessed on 30 December 2018).
16. Schwanitz, V.J.; Piontek, F.; Bertram, C.; Luderer, G. Long-Term Climate Policy Implications of Phasing out Fossil Fuel Subsidies. *Energy Policy* **2014**, *67*, 882–894. [CrossRef]
17. Hossain, M.A.; Hassan, M.S.; Mottaleb, M.A.; Hossain, M. Feasibility of Solar Pump for Sustainable Irrigation in Bangladesh. *Int. J. Energy Environ. Eng. Vol.* **2015**, *6*, 147–155. [CrossRef]
18. Biswas, H.; Hossain, F. Solar Pump: A Possible Solution of Irrigation and Electric Power Crisis of Bangladesh. *Int. J. Comput. Appl.* **2013**, *62*, 0975–8887. [CrossRef]
19. Hasnat, A.; Hasan, M.N.; Hoque, N. *A Brief Study of the Prospect of Hybrid Solar Irrigation System in Bangladesh; ICMIEE-PI*; Khulna University of Engineering & Technology (KUET): Khulna, Bangladesh, 2014; pp. 140285–140286.
20. Hossain, I.; Bari, N.; Miah, S.U. Opportunities and Challenges for Implementing Managed Aquifer Recharge Models in Drought-Prone Barind Tract, Bangladesh. *Appl. Water Sci. Vol.* **2021**, *11*, 15. [CrossRef]
21. Afrin, R.; Hossain, F.; Mamun, S.A. Analysis of Drought in the Northern Region of Bangladesh Using Standardized Precipitation Index (SPI). *Environ. Sci. Nat. Resour.* **2019**, *11*, 199–216. [CrossRef]
22. BGEF. Solar Irrigation Pump. Available online: https://www.greenenergybd.com/sip.php (accessed on 1 June 2018).
23. Prothom Alo. Boro and Rabi Crops Farmers Should Be given Subsidy on Diesel. *Prothom Alo*, 12 November 2021; p. 2.
24. PV Magazine. Solar Irrigation Pumps: Transforming to Smart Irrigation and Improving Agriculture in Bangladesh. Available online: https://www.pv-magazine.com/press-releases/solar-irrigation-pumps-transforming-to-smart-irrigation-and-improving-agriculture-in-bangladesh (accessed on 12 April 2021).
25. ADB. $45.4 Million to Spur Off-Grid Solar Driven Pumping for Irrigation in Bangladesh. Available online: https://www.adb.org/news/454-million-spur-grid-solar-driven-pumping-irrigation-bangladesh (accessed on 12 December 2018).
26. The Business Standard. Electricity Demand May Reach 15,500 MW in Irrigation Season. *The Business Standard*, 30 January 2022; p. 10.
27. Doby, L. Spreading Solar Irrigation in Bangladesh. Available online: https://borgenproject.org/spreading-solar-irrigation-in-bangladesh (accessed on 20 May 2020).
28. Odarno, L. 1.2 Billion People Lack Electricity. Increasing Supply Alone Won't Fix the Problem. Available online: https://www.wri.org/insights/12-billion-people-lack-electricity-increasing-supply-alone-wont-fix-problem (accessed on 18 December 2021).
29. Mirta, A.; Alam, M.F.; Yashodha, Y. *Solar Irrigation in Bangladesh A Situation Analysis Report*; International Water Management Institute (IWMI): Colombo, Sri Lanka, 2021; p. 39.
30. Kanojia, C. Solar Power to Revolutionise Bangladesh Irrigation. *The Financial Express*, 18 March 2019; p. 8.
31. Sajid, E. Solar Irrigation Holds Promise for Low-Cost Farming. *The Business Standard*, 2 December 2019; p. 7.

32. The Financial Express. Solar Irrigation. *The Financial Express*, 2 November 2018; p. 7.
33. Rana, J.; Kamruzzaman, M.; Oliver, M.H.; Akhi, K. Influencing Factors of Adopting Solar Irrigation Technology and Its Impact on Farmers' Livelihood. A Case Study in Bangladesh. *Future Food J. Food Agric. Soc.* **2021**, *9*, 14.
34. SREDA. National Database of Renewable Energy. Available online: http://www.renewableenergy.gov.bd/index.php?id=01&i=4&s=&ag=&di=&ps=1&sg=&fs=&ob=1&submit=Search (accessed on 4 February 2022).
35. SREDA. *Scaling Up Renewable Energy in Low Income Countries (SREP), Investment Plan for Bangladesh*; Sustainable and Renewable Development Authority (SREDA): Washington, WA, USA, 10 November 2015.
36. Sarker, M.N.I.; Ghosh, H.R. Techno-Economic Analysis and Challenges of Solar Powered Pumps Dissemination in Bangladesh. *Sustain. Energy Technol. Assess.* **2017**, *20*, 33–46. [CrossRef]
37. Rana, J.; Kamruzzaman, M.; Oliver, M.H.; Akhi, K. Financial and Factors Demand Analysis of Solar Powered Irrigation System in Boro Rice Production: A Case Study in Meherpur District of Bangladesh. *Renew. Energy* **2021**, *167*, 433–439. [CrossRef]
38. Hossain, M.; Karim, A. *Does Renewable Energy Increase Farmers' Well-Being? Evidence from Solar Irrigation Interventions in Bangladesh; ADBI Working Paper 1096*; Asian Development Bank Institute (ADBI): Tokyo, Japan, 2020; p. 20.
39. Kleemann, L.; Abdulai, A.; Buss, M. Certification and Access to Export Markets: Adoption and Return on Investment of Organic-Certified Pineapple Farming in Ghana. *World Dev.* **2014**, *64*, 79–92. [CrossRef]
40. Zheng, H.; Ma, W. Smartphone-based Information Acquisition and Wheat Farm Performance: Insights from a Doubly Robust IPWRA Estimator. *Electron. Commer. Res.* **2021**, 1–26. [CrossRef]
41. Sanap, S.; Bagal, S.; Pawar, D. Factors Affecting Farmer's Decision of Adoption of Solar Powered Pumps. *Eur. J. Mol. Clin. Med.* **2020**, *7*, 3762–3773.
42. Zhou, D.; Abdullah. The Acceptance of Solar Water Pump Technology among Rural Farmers of Northern Pakistan: A Structural Equation Model. *Cogent Food Agric.* **2017**, *3*, 1280882. [CrossRef]
43. Kumar, V.; Hundal, B.S.; Kaur, K. Factors Affecting Consumer Buying Behaviour of Solar Water Pumping System. *Smart Sustain. Built Environ.* **2019**, *8*, 351–364. [CrossRef]
44. Kumar, V.; Syan, A.S.; Kaur, A.; Hundal, B.S. Determinants of Farmers' Decision to Adopt Solar Powered Pumps. *Int. J. Energy Sect. Manag.* **2020**, *14*, 707–727. [CrossRef]
45. Rahman, S.M.; Faruk, O.; Rahman, H.; Rahman, S.M. Drought Index for the Region Experiencing Low Seasonal Rainfall: An Application to Northwestern Bangladesh. *Arab. J. Geosci. Vol.* **2022**, *15*, 15. [CrossRef]
46. Wikipedia. *Wikipedia, the Free Encyclopedia; Dinajpur District, Bangladesh*. Available online: https://en.wikipedia.org/wiki/Dinajpur_District,_Bangladesh (accessed on 1 January 2022).
47. Islam, S.M.S.; Islam, K.M.A.; Mullick, M.R.A. Drought Hot Spot Analysis Using Local Indicators of Spatial Autocorrelation: An Experience from Bangladesh. *Environ. Chall.* **2022**, *6*, 13. [CrossRef]
48. BBS; WFP. *Poverty Maps of Bangladesh 2016*; Bangladesh Bureau of Statistics (BBS) and World Food Program (WFP): Dhaka, Bangladesh, 2020; p. 57. ISBN 978-984-34-9773-4.
49. BBS. *Population and Housing Census 2011, Zila Report: Dinajpur; Population and Housing Census 2011*; Bangladesh Bureau of Statistics (BBS): Dhaka, Bangladesh, 2015; p. 558.
50. Krejcie, R.V.; Morgan, D.W. Determining Sample Size for Research Activities. *Educ. Psychol. Meas.* **1970**, *38*, 607–610. [CrossRef]
51. BBS. Estimate of Major Crops (2019–2020). Available online: http://www.bbs.gov.bd/site/page/453af260-6aea-4331-b4a5-7b66fe63ba61/Agriculture (accessed on 12 August 2021).
52. McFadden, D. *Chapter Four: Conditional Logit Analysis of Qualitative Choice Behavior. Frontiers in Econometrics*; Zarembka, P., Ed.; Academic Press: New York, NY, USA, 1974; pp. 105–142.
53. Lancaster, K. A New Approach to Consumer Theory. *J. Polit. Econ.* **1966**, *74*, 132–157. [CrossRef]
54. Manski, C.F. The Structure of Random Utility Models. *Theory Decis. Vol.* **1977**, *8*, 229–254. [CrossRef]
55. Hoyos, D. The State of the Art of Environmental Valuation with Discrete Choice Experiments. *Ecol. Econ.* **2010**, *69*, 1595–1603. [CrossRef]
56. Hess, S.; Daly, A.; Batley, R. Revisiting Consistency with Random Utility Maximisation: Theory and Implications for Practical Work. *Theory Decis.* **2018**, *84*, 181–204. [CrossRef] [PubMed]
57. Asfaw, S.; Shiferaw, B.; Simtowe, F.; Lipper, L. Impact of Modern Agricultural Technologies on Smallholder Welfare: Evidence from Tanzania and Ethiopia. *Food Policy* **2012**, *37*, 283–295. [CrossRef]
58. Mariano, M.J.; Villano, R.; Fleming, E. Factors Influencing Farmers' Adoption of Modern Rice Technologies and Good Management Practices in the Philippines. *Agric. Syst.* **2012**, *110*, 41–53. [CrossRef]
59. Sunny, F.A.; Huang, Z.; Karimanzira, T.T.P. Investigating Key Factors Influencing Farming Decisions Based on Soil Testing and Fertilizer Recommendation Facilities (STFRF)—A Case Study on Rural Bangladesh. *Sustainability* **2018**, *10*, 4331. [CrossRef]
60. Rogers, E.M. *Diffusion of Innovations*, 4th ed.; Thee Free Press, A Division of Simon & Schuster Inc.: New York, NY, USA, 1995.
61. Griliches, Z. Hybrid Corn: An Exploration in the Economics of Technological Change. *Econometrica* **1957**, *25*, 501–522. [CrossRef]
62. Greene, W.H. *Econometric Analysis*, 6th ed.; Prentice Hall: New Jersey, NJ, USA, 2007.
63. Feder, G.; Just, E.R.; Zilberman, D. Adoption of Agricultural Innovations in Developing Countries: A Survey. *Econ. Dev. Cult. Change* **1985**, *33*, 255–298. [CrossRef]
64. Green, D.A.G.; Ng'ong'ola, D.H. Factors Affecting Fertilizer Adoption in Less Developed Countries: An Application of Multivariate Logistic Analysis in Malawi. *J. Agric. Econ.* **1993**, *44*, 99–109. [CrossRef]

65. Asfaw, S.; Shiferaw, B.; Simtowe, F.; Haile, M. Agricultural Technology Adoption, Seed Access Constraints and Commercialization in Ethiopia. *J. Dev. Agric. Econ.* **2011**, *3*, 436–477.
66. Angrist, J.D.; Krueger, A.B. Instrumental Variables and the Search for Identification: From Supply and Demand to Natural Experiments. *J. Econ. Perspect.* **2001**, *15*, 69–85. [CrossRef]
67. Imbens, G.W. Nonparametric Estimation of Average Treatment Effects under Exo- Geneity: A Review. *Rev. Econ. Stat.* **2004**, *86*, 4–29. [CrossRef]
68. Wooldridge, J.M. Inverse Probability Weighted Estimation for General Missing Data Problems. *J. Econom.* **2007**, *141*, 1281–1301. [CrossRef]
69. Stata. *STATA Treatment-Effects Reference Manual: Potential Outcomes/Counterfactural Outcomes-Release 16*; Stata Reference Manual; StataCorp LLC: College Station, TX, USA, 2013; p. 160.
70. Wooldridge, J.M. *Econometric Analysis of Cross Section and Panel Data*, 2nd ed.; MIT Press: Cambridge, MA, USA, 2010.
71. Imbens, G.W.; Wooldridge, J.M. Recent Developments in the Econometrics of Program Evaluation. *J. Econ. Lit.* **2009**, *47*, 5–86. [CrossRef]
72. Rosenbaum, P.R.; Rubin, D.B. The Central Role of the Propensity Score in Observational Studies for Causal Effects. *Biometrika* **1983**, *70*, 41–55. [CrossRef]
73. Manda, J.; Gardebroek, C.; Kuntashula, E.; Alene, A.D. Impact of Improved Maize Varieties on Food Security in Eastern Zambia: A Doubly Robust Analysis. *Rev. Dev. Econ.* **2018**, *22*, 1709–1728. [CrossRef]
74. Hirano, K.; Imbens, G.W. Estimation of Causal Effects Using Propensity Score Weighing: An Application to Data on Right Heart Catherization. *Health Serv. Outcomes Res. Methodol. Vol.* **2001**, *2*, 259–278. [CrossRef]
75. Pal, B.D.; Kapoor, S. *Intensification of Climate- Smart Agriculture Technology in Semi-Arid Regions of India*; Working Paper No. 321; CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS): Wageningen, The Netherlands, 2020; p. 35.
76. Ntshangase, N.L.; Muroyiwa, B.; Sibanda, M. Farmers' Perceptions and Factors Influencing the Adoption of No-Till Conservation Agriculture by Small-Scale Farmers in Zashuke, KwaZulu-Natal Province. *Sustainability* **2018**, *10*, 555. [CrossRef]
77. Tiwari, K.R.; Sitaula, B.K.; Nyborg, I.L.P.; Paudel, G.S. Determinants of Farmers' Adoption of Improved Soil Conservation Technology in a Middle Mountain Watershed of Central Nepal. *Environ. Manage* **2008**, *42*, 210–222. [CrossRef] [PubMed]
78. Chuchird, R.; Sasaki, N.; Abe, I. Influencing Factors of the Adoption of Agricultural Irrigation Technologies and the Economic Returns: A Case Study in Chaiyaphum Province, Thailand. *Sustain. MDPI Open Access J.* **2017**, *9*, 1524. [CrossRef]
79. Caswell, M.; Fuglie, K.; Ingram, C.; Jans, S.; Kascak, C. *Adoption of Agricultural Production Practices: Lessons Learned from the US. Department of Agriculture Area Studies Project*; Agriculture Economic Report AER-792; US Department of Agriculture, Resource Economics Division, Economic Research Service: Washington, WA, USA, 2001; p. 116.
80. Zeng, D.; Alwang, J.; Norton, G.; Jaleta, M.; Shiferaw, B.; Yirga, C. Land Ownership and Technology Adoption Revisited: Improved Maize Varieties in Ethiopia. *Land Use Policy* **2018**, *72*, 270–279. [CrossRef]
81. Endrias, G.; Ayalneh, B.; Belay, K.; Elias, E. Determinants of Farmers' Decision on Soil Fertility Management Options for Maize Production in Southern Ethiopia. *Am. J. Exp. Agric.* **2013**, *3*, 226–239.
82. Reza, S.; Hossain, E. Factors Affecting Farmers' Decisions on Fertilizer Use: A Case Study of Rajshahi District in Bangladesh. *Bangladesh J. Polit. Econ.* **2013**, *29*, 211–221.
83. Sarker, M.R.; Galdos, M.V.; Challinor, A.J.; Hossain, A. A Farming System Typology for the Adoption of New Technology in Bangladesh. *Food Energy Secur.* **2021**, *10*, e287. [CrossRef]
84. Challa, M.; Tilahun, U. Determinants and Impacts of Modern Agricultural Technology Adoption in West Wollega: The Case of Gulliso District. *J. Biol. Agric. Healthc.* **2014**, *4*, 63–77.
85. Araya, G.B.; Holden, S.T. *The Impact of Ethiopia's Productive Safety Net Program on Fertilizer Adoption by Small Holder Farmers in Tigray, Northern Ethiopia*; International Association of Agricultural Economists (IAAE): Vancouver, BC, USA, 2018; p. 29.
86. Pandey, V.L.; Mishra, V. Adoption of Zero Tillage Farming: Evidences from Haryana and Bihar. *SSRN Electron. J.* **2004**, *2004*, 17.
87. Gebeyehu, M.G. The Impact of Technology Adoption on Agricultural Productivity and Production Risk in Ethiopia: Evidence from Rural Amhara Household Survey. *Open Access Libr. J.* **2016**, *3*, 1–14. [CrossRef]
88. Deressa, T.T.; Hassan, R.M.; Ringler, C. Perception of and Adaptation to Climate Change by Farmers in the Nile Basin of Ethiopia. *J. Agric. Sci.* **2011**, *149*, 23–31. [CrossRef]
89. Feder, G.; Slade, R. The Acquisition of Information and the Adoption of New Technology. *Am. J. Agric. Econ.* **1984**, *66*, 312–320. [CrossRef]
90. Bairagi, S.; Bhandari, H.; Das, S.B.; Mohanty, S. Impact of Submergence-Tolerant Rice Varieties on Smallholders' Income and Expenditure: Farm-Level Evidence from Bangladesh. Selected Paper Prepared for Presentation in Agricultural & Applied Economics Association Annual Meeting 2018. Washington, D.C. 2018. Available online: https://www.researchgate.net/publication/326263766_Impact_of_Submergence-Tolerant_Rice_Varieties_on_Smallholders\T1\textquoteright_Income_and_Expenditure_Farm-Level_Evidence_from_Bangladesh/citations (accessed on 1 August 2018).
91. Kassie, M.; Teklewold, H.; Jaleta, M.; Marenya, P.; Erenstein, O. Understanding the Adoption of a Portfolio of Sustainable Intensification Practices in Eastern and Southern Africa. *Land Use Policy* **2015**, *42*, 400–411. [CrossRef]
92. Simtowe, F.; Zeller, M. The Impact of Access to Credit on the Adoption of Hybrid Maize in Malawi: An Empirical Test of an Agricultural Household Model under Credit Market Failure. In Proceedings of the 2007 Second International Conference, Accra, Ghana, 20–22 August 2007; African Association of Agricultural Economists (AAAE): Nairobi, Kenya. [CrossRef]

93. Mottaleb, K.A.; Krupnik, T.J.; Erenstein, O. Factors Associated with Small-Scale Agricultural Machinery Adoption in Bangladesh: Census Findings. *J. Rural Stud.* **2016**, *46*, 155–168. [CrossRef] [PubMed]
94. Albrecht, D.E.; Ladewig, H. Adoption of Irrigation Technology: The Effects of Personal, Structural, and Environmental Variables. *J. Rural Soc. Sci.* **1985**, *3*, 26–41.
95. Genius, M.; Koundouri, P.; Nauges, C.; Tzouvelekas, V. Information Transmission in Irrigation Technology Adoption and Diffusion: Social Learning, Extension Services, and Spatial Effects. *Amer J. Agric. Econ.* **2013**, *96*, 328–344. [CrossRef]
96. Jansson, J.; Pettersson, T.; Mannberg, A.; Brännlund, R.; Lindgren, U. Adoption of Alternative Fuel Vehicles: Influence from Neighbors, Family and Coworkers. *Transp. Res. Part Transp. Environ.* **2017**, *54*, 61–73. [CrossRef]
97. Mendola, M. Agricultural Technology Adoption and Poverty Reduction: A Propensity-Score Matching Analysis for Rural Bangladesh. *Food Policy* **2007**, *32*, 372–393. [CrossRef]
98. Irfan, M.; Zhao, Z.Y.; Rehman, A.; Ozturk, I.; Li, H. Consumers' Intention-Based Influence Factors of Renewable Energy Adoption in Pakistan: A Structural Equation Modeling Approach. *Environ. Sci. Pollut. Res. Vol.* **2020**, *28*, 432–445. [CrossRef] [PubMed]
99. Liu, W.; Wang, C.; Mol, A.P.J. Rural Public Acceptance of Renewable Energy Deployment: The Case of Shandong in China. *Appl. Energy* **2013**, *102*, 1187–1196. [CrossRef]
100. Maddala, G.S. *Limited-Dependent and Qualitative Variables in Econometrics*; Cambridge University Press: New York, NY, USA, 1983.
101. Baidu-Forson, J. Factors Influencing Adoption of Land-Enhancing Technology in the Sahel: Lessons from a Case Study in Niger. *Agric. Econ.* **1999**, *20*, 231–239.
102. Li, H.; Huang, D.; Ma, Q.; Qi, W.; Li, H. Factors Influencing the Technology Adoption Behaviours of Litchi Farmers in China. *Sustainability* **2019**, *12*, 271. [CrossRef]
103. Abosede, J. Agricultural Technology Adoption, Extension Service, Impact on Productivity: Case Study of Smallholder Farmers in Uganda. Master's Thesis, Universitanda, Louvain-la-Neuve, Belgium, 2021.
104. Salazar, C.; Rand, J. Production Risk and Adoption of Irrigation Technology: Evidence from Small-Scale Farmers in Chile. *Lat. Am. Econ. Rev. Vol.* **2016**, *25*, 1–37. [CrossRef]
105. Asfaw, D.; Neka, M. Factors Affecting Adoption of Soil and Water Conservation Practices: The Case of Wereillu Woreda (District), South Wollo Zone, Amhara Region, Ethiopia. *Int. Soil Water Conserv. Res.* **2017**, *5*, 273–279. [CrossRef]
106. Uddin, A. Youth Engagement in Agriculture: Bangladesh Perspective. *The Business Standard*, 27 August 2020; p. 25.
107. Kabunga, N.S.; Dubois, T.; Qiam, M. Heterogeneous Information Exposure and Technology Adoption: The Case of Tissue Culture Bananas in Kenya. *Agric. Econ.* **2012**, *43*, 473–485. [CrossRef]
108. Ndiritu, S.W.; Kassie, M.; Sheferaw, B. Are There Systematic Gender Differences in the Adoption of Sustainable Agricultural Intensification Practices? Evidence from Kenya. *Food Policy* **2014**, *49*, 117–127. [CrossRef]
109. Krishnan, P.; Patnam, M. Neighbors and Extension Agents in Ethiopia: Who Matters More for Technology Adoption? *Am. J. Agric. Econ.* **2014**, *96*, 308–327. [CrossRef]
110. Birthal, P.S.; Kumar, S.; Negi, D.S.; Roy, D. The Impacts of Information on Returns from Farming: Evidence from a Nationally Representative Farm Survey in India. *Agric. Econ.* **2015**, *46*, 549–561. [CrossRef]
111. Kazal, M.M.H.; Rahman, M.S.; Rayhan, S.J. Determinants and Impact of the Adoption of Improved Management Practices: Case of Freshwater Prawn Farming in Bangladesh. *Aquac. Rep.* **2020**, *18*, 100448. [CrossRef]